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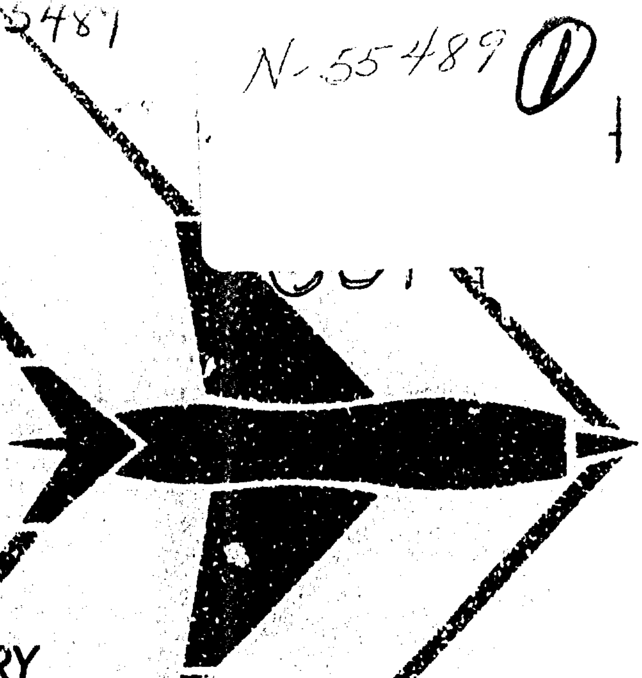
CHARACTERISTICS OF SIX RESEARCH WIND TUNNELS OF THE AMES AERONAUTICAL LABORATORY



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CHARACTERISTICS OF SIX RESEARCH WIND TUNNELS OF THE AMES AERONAUTICAL LABORATORY

INTRODUCTION

This document was prepared in response to requests of the aircraft industry for information on NACA research wind tunnels. Characteristics are given of six selected wind tunnels of the NACA Ames Aeronautical Laboratory located at Moffett Field, California. A table summarizing certain important characteristics of these wind tunnels is given immediately following the introduction. Characteristics of nine Langley wind tunnels are given in a separate volume (ref. 1).

Wind tunnels, accessory equipment, and instrumentation are continually being improved as new and better techniques are developed. It is essential therefore that agencies planning models for tests in the wind tunnels described in this manual consult the staff of the Ames Aeronautical Laboratory to take advantage of the latest techniques and equipment. Details such as balance dimensions and model-mounting dimensions can be supplied at that time. In some cases models can be designed to accommodate tests in more than one NACA wind tunnel.

NACA research facilities in general are available for use by other Government agencies, provided the projects are of sufficient importance to warrant interference with the NACA research program, and, provided further, that other suitable facilities are not available, either commercially or in the Government. A complete index of transonic and supersonic wind tunnels in the United States is given in reference 2.

Proprietary tests on a fee basis are conducted in NACA research facilities only in exceptional circumstances. On the other hand, testing time is reserved in the NACA Unitary Plan Wind Tunnels for proprietary tests on a fee basis if the need arises (ref. 3). It is the policy of NACA not to compete with commercially available facilities.

Requests for all projects should be addressed to the Director, National Advisory Committee for Aeronautics, 1512 H Street, N. W., Washington 25, D. C. The usual practice involves conferences between the NACA, the interested contractor, and - in the case of Government projects - the sponsoring branch of the Government. Advance consultation with the NACA should always take place prior to making definite plans for tests in NACA facilities.

Requests for NACA tests from the Air Force, Navy, and Army are coordinated by two NACA allocation and priority groups, one on aircraft and missiles projects and one on propulsion projects. Each group comprises one member each from the NACA, Air Force, Navy, and Army. Requests for

tests from military contractors should be processed via the appropriate military member of the pertinent allocation and priority group. Currently, the Air Force members are located at the Wright Air Development Center, and the Navy members at the Bureau of Aeronautics. The Army member for the aircraft and missiles group is located at the Ballistic Research Laboratories, Aberdeen Proving Ground, and for the propulsion group in the Office of the Chief of Ordnance.

References

1. Anon: Characteristics of Nine Research Wind Tunnels of the Langley Aeronautical Laboratory. NACA, 1957.

2. Anon: Characteristics of Major United States Transonic and Supersonic Wind Tunnels and Engine Test Facilities. CAF 201/2, Office of Assist. Secy. Defense, Res. and Dev., Oct. 3, 1956. (Distributed by ASTIA.)

3. Anon: Manual for Users of the Unitary Plan Wind Tunnel Facilities of the National Advisory Committee for Aeronautics. NACA, 1956.

TABLE I.- SUMMARY OF WIND-TUNNEL CHARACTERISTICS

Wind tunnel	Test section size, ft	Mach no.	Stagnation pressure, atm.	Stagnation temperature, °F	Reynolds no. per ft, million	Dynamic pressure, lb/sq ft	Typical model size[1]	Model support system	Flow visualization
40- by 80-ft wind tunnel	40 high, 80 wide with semicircular sides, 80 long	0 to 0.30	1.00	30 to 120	0 to 2.1	0 to 135	72 ft span 60 ft long 600 sq ft wing area	struts	—
14-foot transonic wind tunnel	13.50 high 13.82 wide 33.75 long	0.60 to 1.20	1.00	30 to 180	2.8 to 3.7	400 to 900	6.75 ft span 0.9 sq ft frontal area	sting	schlieren
12-foot pressure wind-tunnel	12 diam with 11.31 across flats, 18 long	0 to 0.96	0.16 to 5	30 to 185	0 to 10.5 dependent on M	0 to 600 dependent on M	10 ft span 4 sq ft wing area	sting, semispan, through	—
6- by 6-ft supersonic wind tunnel	6 high 6 wide 14.42 long	0.60 to 2.25	0.27 to 1.09	30 to 110	1 to 5 dependent on M	200 to 1000 dependent on M	3 ft span 5 ft long 0.20 sq ft frontal area	sting	schlieren
2- by 2-ft transonic wind tunnel	2 high 2 wide 4.83 long	0.60 to 1.40	0.34 to 2.38	70 to 120	4.8 to 8.7 dependent on M	150 to 1700 dependent on M	0.02 sq ft frontal area	sting	schlieren
1- by 3-ft supersonic wind tunnel, continuous	3 high 1 wide 5.5 long	0.40 to 0.90 and 1.40 to 4.00	0.14 to 4.00	60 to 140	0.2 to 12 dependent on M	600 to 2150 dependent on M	0.66 ft span 1.33 ft long	sting, semispan, through	schlieren, shadowgraph
1- by 3-ft supersonic wind tunnel, blowdown	3 high 1 wide 5.5 long	0.40 to 0.90 and 1.40 to 4.00	1.00 to 5.78	0 to 70	7 to 28 dependent on M	850 to 4400 dependent on M	0.58 ft semispan 2.08 ft long	sting, semispan, through	—

[1]Depends on purpose of investigation and should be determined by consultation.

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THE AMES
40- BY 80- FOOT WIND TUNNEL

Ames Aeronautical Laboratory
Moffett Field, California

AMES 40- BY 80-FOOT WIND TUNNEL

GENERAL DESCRIPTION

The Ames 40- by 80-foot wind tunnel (fig. 1) was designed to study the low-speed characteristics of large-scale models or full-scale aircraft. It has a closed 40- by 80-foot test section. The return passage is single and is closed. If desired, a portion of the air may be exhausted through controllable vents in the return passage and this air is replaced from the atmosphere through a second set of vents. This feature allows for removal of contaminants from the air and for limited cooling of the tunnel air, but is not sufficient for accurate temperature control.

The air is driven by six 40-foot diameter fans which are powered by six 6,000-horsepower electric motors. The drive system may be operated continuously at any power output up to the maximum of 36,000 horsepower. The speed of the motors is continuously variable over the operating range.

TEST SECTION

The test section is 40 feet high by 80 feet wide and is 80 feet long in the streamwise direction. Its cross-stream shape is best described as a 40-foot square with the addition on each side of a semicircle of 20-foot radius. The general layout of the test section and surrounding test chamber is shown in figure 2.

TEST CONDITIONS

Airspeed	0 to 230 miles per hour, continuously variable
Pressure, stagnation	Atmospheric
Reynolds number	0 to 2.1×10^6 per foot with 60° F stagnation temperature and 29.9 inches of Hg barometric pressure (See fig. 3.)
Temperature, stagnation	Uncontrolled. Dependent upon seasonal atmospheric variations; also affected by operation of internal-combustion engines in models. Generally 30° F to 120° F.

MODEL-SUPPORT SYSTEM

Models are supported on two main struts and a collapsible tail strut which, in turn, are supported on a frame below the test-section floor (see fig. 2(b)). The main struts can be moved streamwise differentially

and the tail strut moved cross-streamwise to yaw the model. The angle of attack of the model can be changed by collapsing or extending the tail strut.

The range of the angle-of-attack variations may be limited by any one of three conditions; namely, (1) angular limitations of the ball sockets (see fig. 4(a)), (2) the maximum and minimum heights of the tail strut (further affected by tail length (see fig. 4(b)), and (3) physical clearances within the test section for larger models. The main-strut ball and socket limits of $\pm 22.5^{\circ}$ can be offset any amount up to $\pm 20^{\circ}$ by insertion of wedges at the model attachment pad. Limits for any proposed arrangement can be determined from the information given in figure 4.

Limitations upon the angle of yaw are imposed by the available streamwise and cross-streamwise motion of the main struts or by maximum angle of inclination of the tail strut (see fig. 4(b)).

MODELS

A typical model mounted in the test section is shown in figure 2(c). Only very general model requirements will be stated here. It is essential that the wind-tunnel staff be consulted early during the planning of any investigation to assure that the latest of the continuously evolving techniques and equipment are used to best advantage. Details of mounting dimensions, of instrumentation hookups, and of other equipment can be supplied at the time of such consultation.

The optimum size of a model depends on the purpose of the investigation and shall be determined by consultation. At present, the following maximums are recommended:

Span	72 ft (maximum test section width, 80 ft)
Wing area	Approximately 600 sq ft
Weight	30,000 lb
Length	60 ft

The model structure and the mechanisms and instrumentation within the model must function reliably over the following range of environment in the test section: stagnation temperatures from as low as 30° F to as high as 120° F; temperature rise during a run as much as 30° F; dynamic pressure and air density as shown in figure 5.

It is desirable that models incorporating engines or controllable mechanisms be controlled from the control room shown in figure 2. Details of hookups for these controls should be determined by consultation with the wind-tunnel staff.

INSTRUMENTATION

Balances

The over-all steady-state forces and moments acting on models are measured by a system of beam balances. A schematic representation of the general arrangement is shown in figure 6.

Forces and moments on components such as control surfaces are usually measured by strain-gage devices designed as part of each model. The strain gages should be designed in accordance with specifications which can be obtained from the Laboratory to insure compatibility with the recording equipment.

The allowable loads on the main balance are as follows:

Strut	Allowable loads per strut, pounds (Aerodynamic plus model dead weight)				
	Down	Up	Side	Drag	Thrust
Heavy main, no. 1	35,000	15,000	4,000	8,000	8,000
Light main, no. 2	18,000	8,000	2,000	4,000	4,000
Tail	18,000	18,000	(1)	(1)	(1)

[1]The tail strut is mounted in a gimbal and, hence, cannot transmit side, drag, or thrust loads.

Manometers

Six 80-tube water manometers, two 80-tube alkazene manometers, and one 80-tube mercury manometer are available normally. More can generally be provided when needed. The working height is 54 inches. The scales have 0.10-inch divisions. Recording is by photography.

Pressure fluctuations can be measured and recorded with special equipment at the Laboratory. Arrangement for installation and use of this equipment must be made by consultation with the wind-tunnel staff.

Data Recording and Reduction

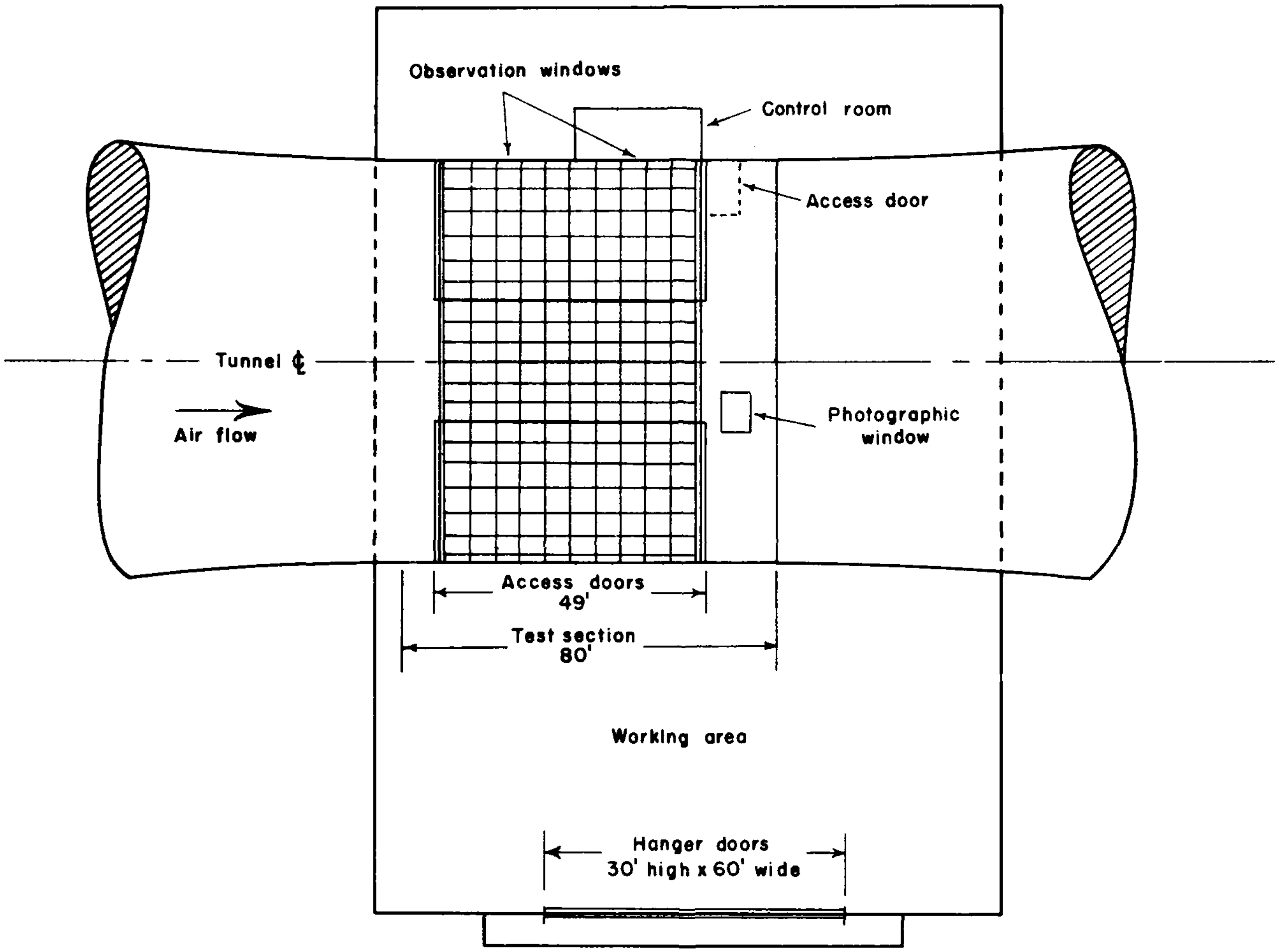
Forces and moments.- Data are recorded by printing. At present, they are generally transferred manually to punched cards and the coefficients are computed by machine at the Laboratory's computing center.

Pressures.- Pressures are recorded by photographing multiple-tube manometers. The photographs are read manually with a special device which automatically computes and semiautomatically plots the coefficients.

Flow Visualization

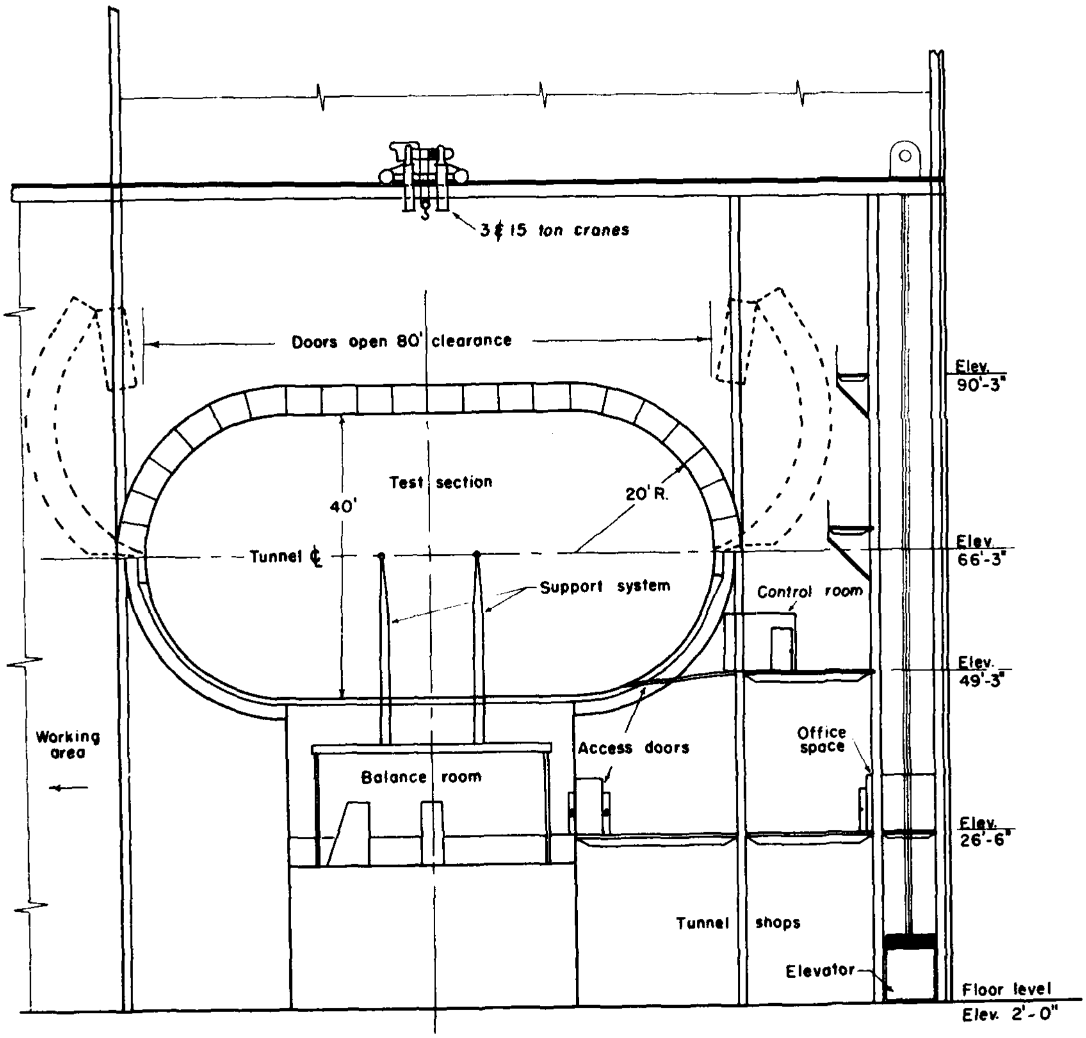
Windows are provided at many locations along the test section for observation of the model (fig. 2(c)). A window (fig. 2(a)) is provided in the top of the test section to permit photographs of the tufts to be made. Permanent facilities for model illumination are provided.

Figure 1.- Scale model of the Ames 40- by 80-foot wind tunnel.



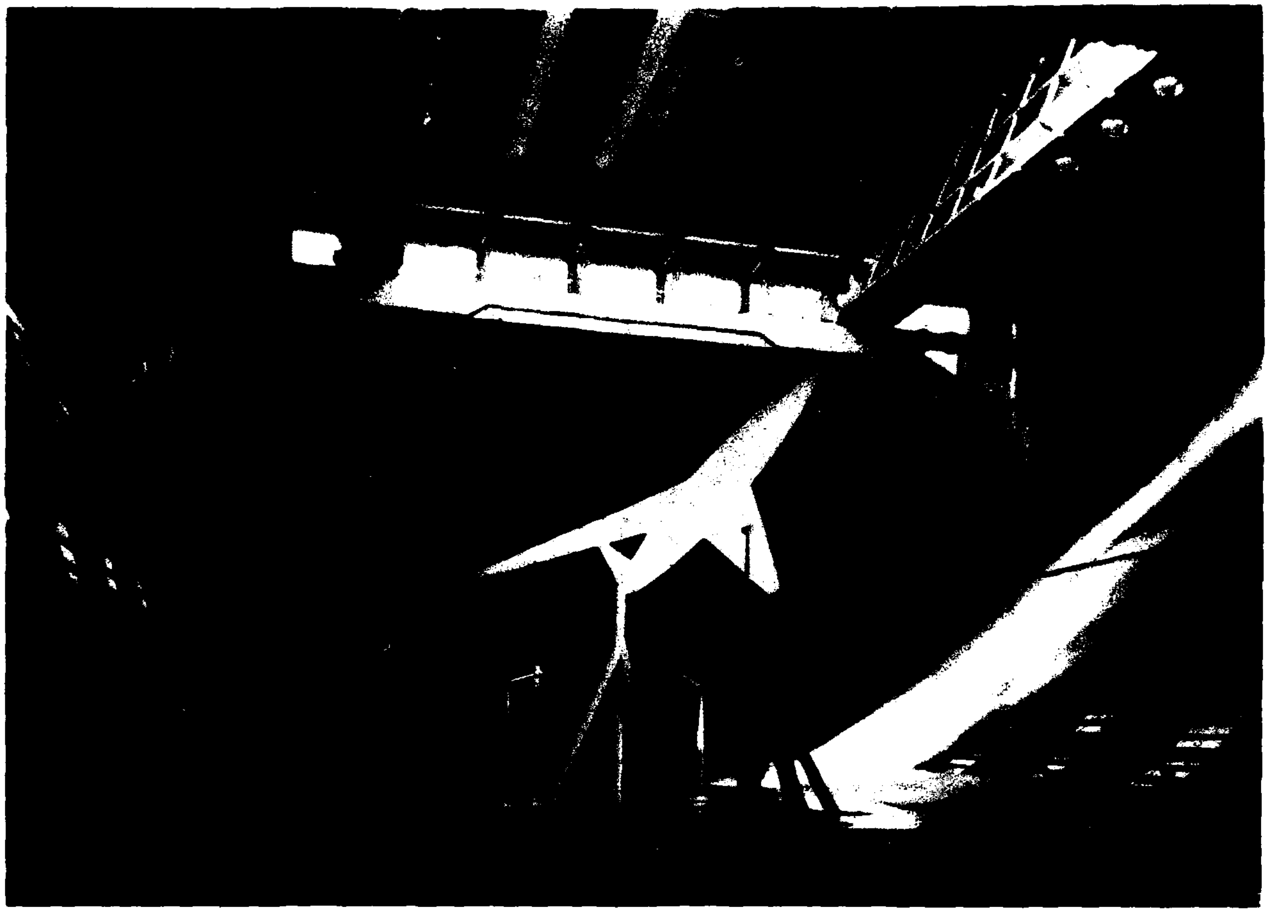
(a) Plan view.

Figure 2.- General arrangement of the Ames 40- by 80-foot wind tunnel test chamber.



(b) Elevation view.

Figure 2.- Continued.



(c) Looking downstream in the test section.

Figure 2.- Concluded.

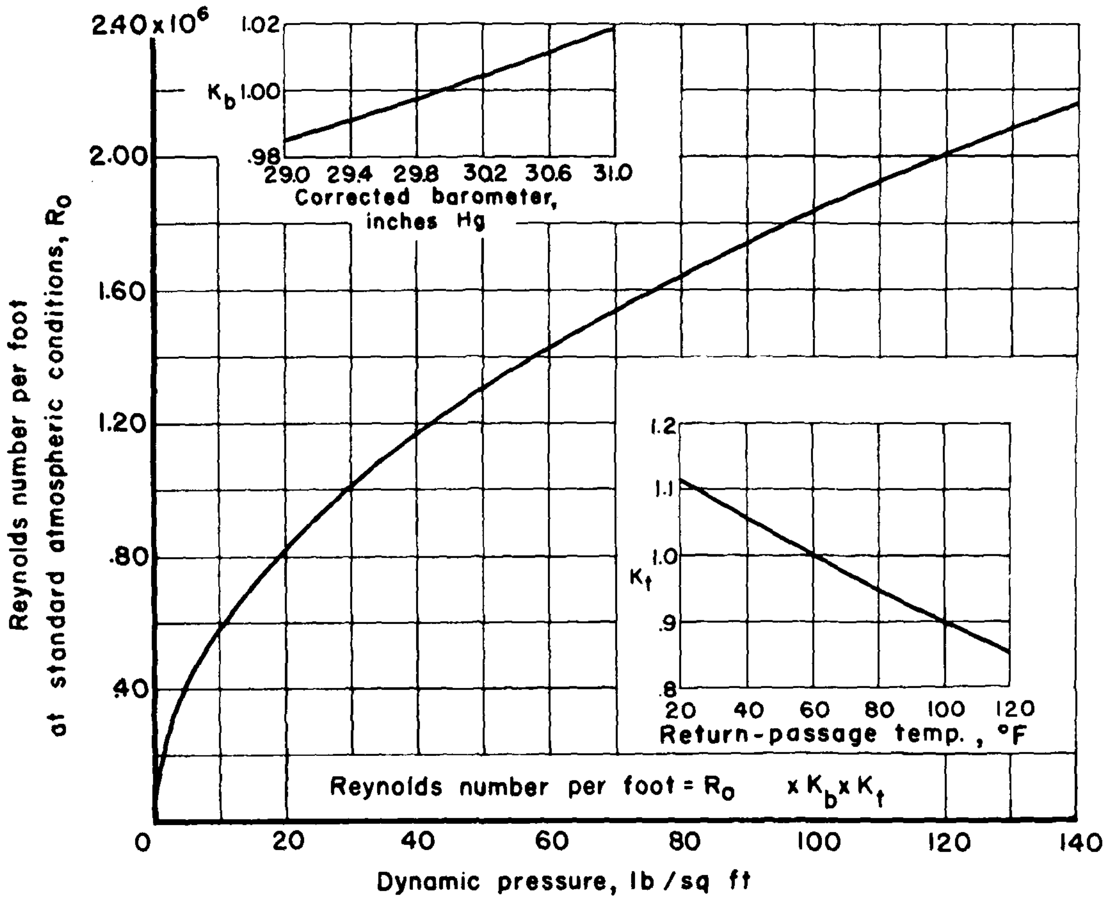
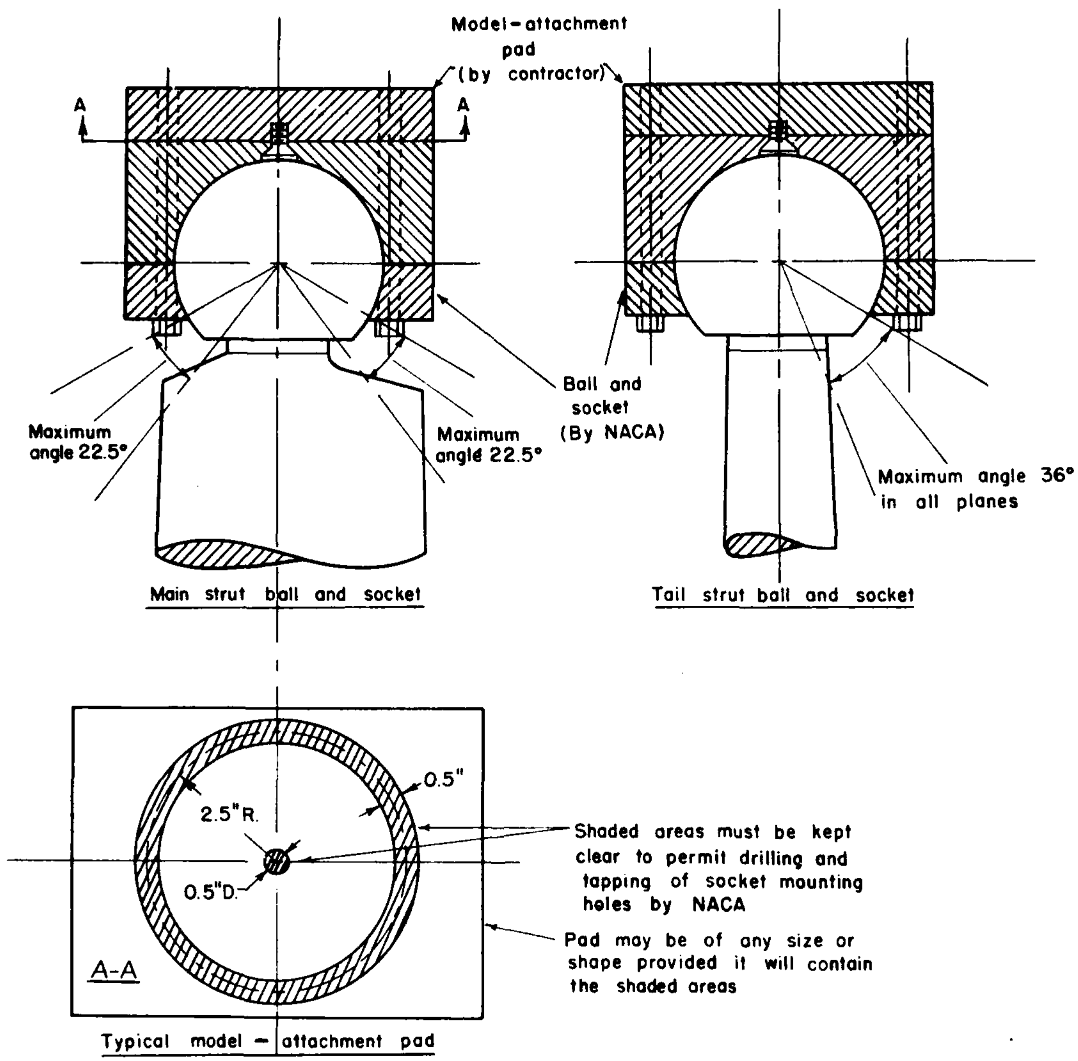
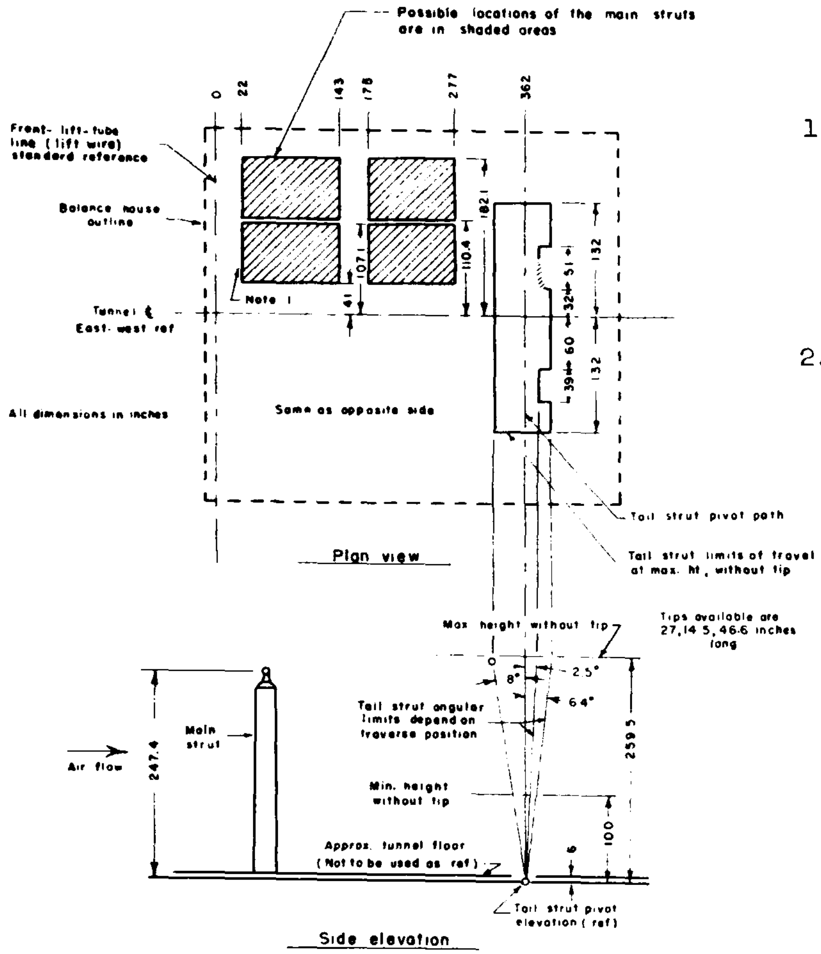


Figure 3.- Variation of Reynolds number with test-section dynamic pressure for the Ames 40- by 80-foot wind tunnel.



(a) Angular limitations of model-support strut tips.

Figure 4.- Limitations and possible arrangements of the model-support system in the Ames 40- by 80-foot wind tunnel.



NOTES

1. If the airplane is to be tested only at zero yaw, the main struts may be located within the indicated boxes. (The present system cannot accommodate airplanes having treads[1] from 214.25 to 220.75 inches.) Models having tail lengths[2] from 187 to 225 inches may be severely limited in angle of attack.

2. If the airplane is to be yawed, the yaw angle available is determined by the airplane tread and tail length and the proximity of the main struts to the boundaries described in note 1. The maximum allowable movements of the main struts are 19 inches cross stream and 54 inches streamwise. It is suggested that the available yaw angle be estimated by the 40- by 80-foot wind-tunnel staff upon receipt of values of tread and tail length compatible with the above requirements and the structure of the model.

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[1]For wind-tunnel purposes, the tread is defined as the distance between the main strut attachment points.

[2]Tail length is defined as the distance from the main strut center line to the center line of the tail strut ball socket.

(b) Limitations of model tread, tail length, and yaw.

Figure 4.- Concluded.

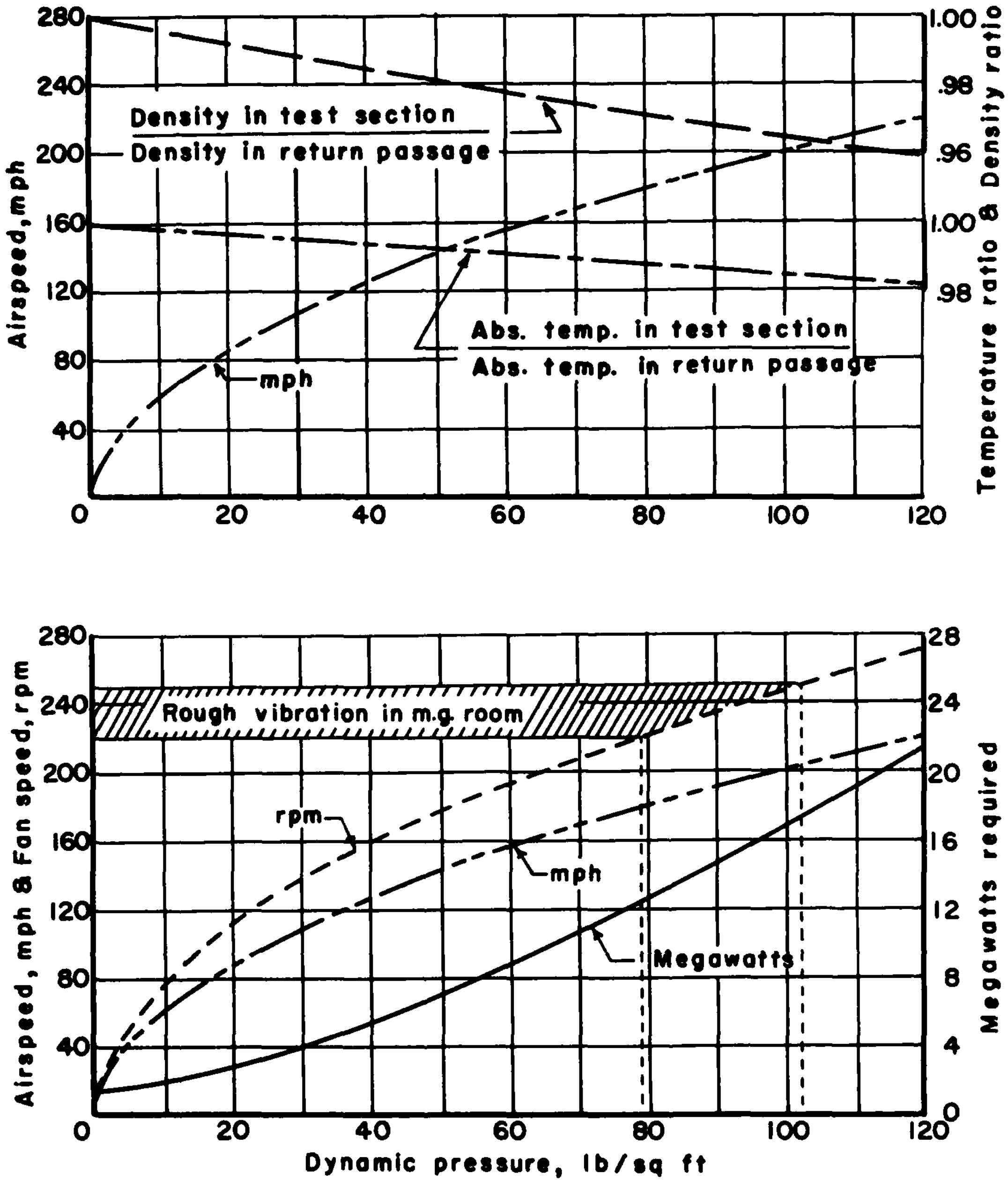

Figure 5.- Variation of test-section conditions and operating characteristics with test-section dynamic pressure at standard atmospheric conditions; Ames 40- by 80-foot wind tunnel.

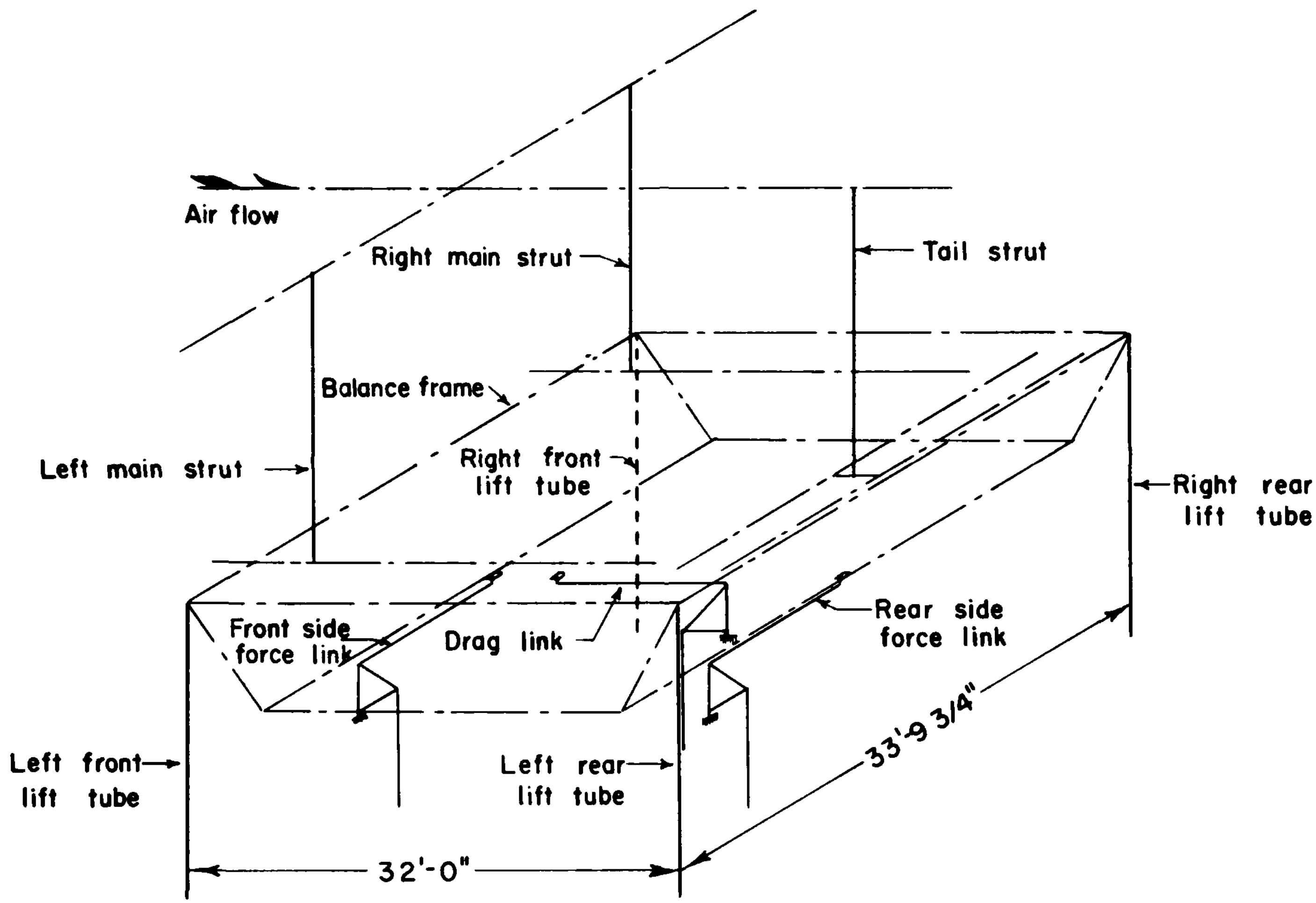

Figure 6.- Schematic representation of the 40- by 80-foot wind tunnel balance system.

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THE AMES
14- FOOT TRANSONIC WIND TUNNEL

14-FT TRANSONIC

Ames Aeronautical Laboratory

Moffett Field, California

NACA

AMES 14-FOOT TRANSONIC WIND TUNNEL

GENERAL DESCRIPTION

The Ames 14-foot transonic wind tunnel (fig. 1) was created by extensive modification of the former Ames 16-foot high-speed wind tunnel. It has a flexible-wall nozzle to generate the supersonic airspeeds and a perforated test section to prevent choking and to alleviate the reflection of shock waves. The return passage is single, and is closed except at the air exchanger where a controlled portion of the flow is exhausted and replaced from the atmosphere to maintain the desired air temperature.

The air is driven by a three-stage, axial-flow compressor which is powered by three electric motors mounted in tandem outside the wind tunnel. The drive system is rated 110,000 horsepower continuously or 132,000 horsepower for one hour. The speed of the motors is continuously variable over the operating range.

TEST SECTION

The test section is approximately square in cross section with the dimensions shown in figure 2. The walls are perforated to prevent choking and to minimize reflection of shock waves.

TEST CONDITIONS

Mach number	0.6 to 1.2, continuously variable
Pressure, stagnation	Atmospheric
Reynolds number	2.8×10^6 to 3.7×10^6 per foot with 180° F stagnation temperature. (See fig. 3.)
Temperature, stagnation	Controllable by throttling the air exchanger. Generally about 180° F to avoid condensation of moisture in the test section.

MODEL-SUPPORT SYSTEM

Models are supported from the rear by stings as illustrated in figures 2 and 4. The stings are, in turn, supported from a vertical strut which is downstream of the test section. Two portions of the strut can be moved differentially (fig. 4) to change model angle of attack. Also, the two portions can be moved equally to change the elevation of the

model. This feature is used to bring the sting and the model to a convenient working height. The model angle of attack can be varied from -15° to $+24^\circ$ by the differential motion. This range can be offset any amount up to $\pm 10^\circ$ by manual adjustment, during shutdown, of eccentric bushings in the nose of the sting-support body. Yaw angles up to $\pm 10^\circ$ are effected by different manual adjustment of the same eccentric bushings. Larger yaw at manually adjusted angles of attack, and its variation during wind-tunnel operation, can be had by mounting the model with its wing span vertical so that yaw is varied by the angle-of-attack mechanism.

MODELS

A typical model mounted in the test section is shown in figure 5. Only very general model requirements will be stated here. It is essential that the wind-tunnel staff be consulted early during the planning of any investigation to assure that the latest of the continuously evolving techniques and equipment will be used to best advantage. Details of mounting dimensions, of available balances, and of other equipment and instruments can be supplied at the time of such consultation.

The optimum size of a model depends on the purpose of the investigation and shall be determined by consultation. At the present time, the following are generally recommended as maximums:

Frontal area	0.9 sq ft
Length behind end of sting	3.25 ft
Length forward of end of sting	9.75 ft
Span	6.75 ft

The model structure and the mechanisms and instrumentation within the model must function reliably over the following range of environment in the test section: stagnation temperatures which rise rapidly from as low as 30° F to about 180° F as the wind tunnel is brought up to speed; humidity up to 100 percent; and the static pressure, dynamic pressure, and air density which are shown in figure 6.

INSTRUMENTATION

Balances

The over-all steady-state forces and moments acting on models are measured by strain-gage balances mounted on the end of the supporting sting within the models. Balances from 2.5 to 4.0 inches in diameter, with total lift capacities of about 2,800 and 8,000 pounds, respectively, are generally used in this wind tunnel. Details of balances available at the Laboratory can be ascertained by consultation with the wind-tunnel staff.

Forces and moments on components such as control surfaces are usually measured by strain-gage devices designed as part of each model. The strain gages should be designed in accordance with specifications which can be obtained from the Laboratory to insure compatibility with the recording equipment.

The Laboratory has some special equipment for the measurement of dynamic stability derivatives.

Manometers

Three 80-tube mercury manometers and two 60-tube tetrabromoethane manometers are available. More can generally be provided when needed. The working heights are 33 inches for mercury and 60 inches for tetrabromoethane. Recording is by photography. Both types of manometers have scales with 0.10-inch divisions.

The Ames Laboratory also has a 32-channel automatic system which measures pressures and computes and plots coefficients. In addition, it integrates the pressure coefficients so as to compute section lift and moment coefficients and prints these on a tape. Two of the channels are required for reference pressures, leaving 30 for pressure distribution. By the use of available multiple valves, as many as 90 pressures can be measured, computed, and plotted in approximately two minutes elapsed time. This pressure computer and plotter is used by other Ames wind tunnels also; therefore, its availability must be ascertained for each project.

Pressure fluctuations can be measured and recorded with special equipment at the Laboratory. Arrangements for installation and use of this equipment must be made by consultation with the wind-tunnel staff.

Data Recording and Reduction

Forces and moments.- Installed at the wind-tunnel control benchboard are eight channels of equipment for exciting electrical-resistance strain gages and reading their outputs. In the usual case six of these channels are used with a six-component strain-gage balance, leaving two components for other uses such as measuring wing bending moments or hinge moments.

The outputs are indicated on dials and printed on a single wide paper tape as 0 to 1,000 counts. The device also drives analog-to-digital converters to record the output with a card punch. From the cards, the coefficients can then be computed, tabulated, and plotted by machine at the Laboratory's computing center.

For immediate reviewing of the test results, an analog computer and plotter will be available. The plots from this machine will not be completely corrected or sufficiently accurate for final use, but they may be used for continuous monitoring during tests.

Pressures.- A pressure-coefficient computer and plotter has been described hereinbefore. For reading photographs of the liquid-in-glass manometers and computing and plotting the coefficients, several methods are available. All these methods involve some manual operations. The method used depends on the circumstances in each case.

Flow Visualization

In each side of the test section and in the pressure-tight enclosure are windows 8 feet high by 11 feet long (fig. 4) of ground and polished optical glass. These areas are subdivided into openings each 7.5 inches high by 24 inches long. They are used for direct visual observation and for schlieren and shadowgraph visualization of the flow. The mirrors of the schlieren system are 40 inches in diameter and can be alined across any part of the large window area.

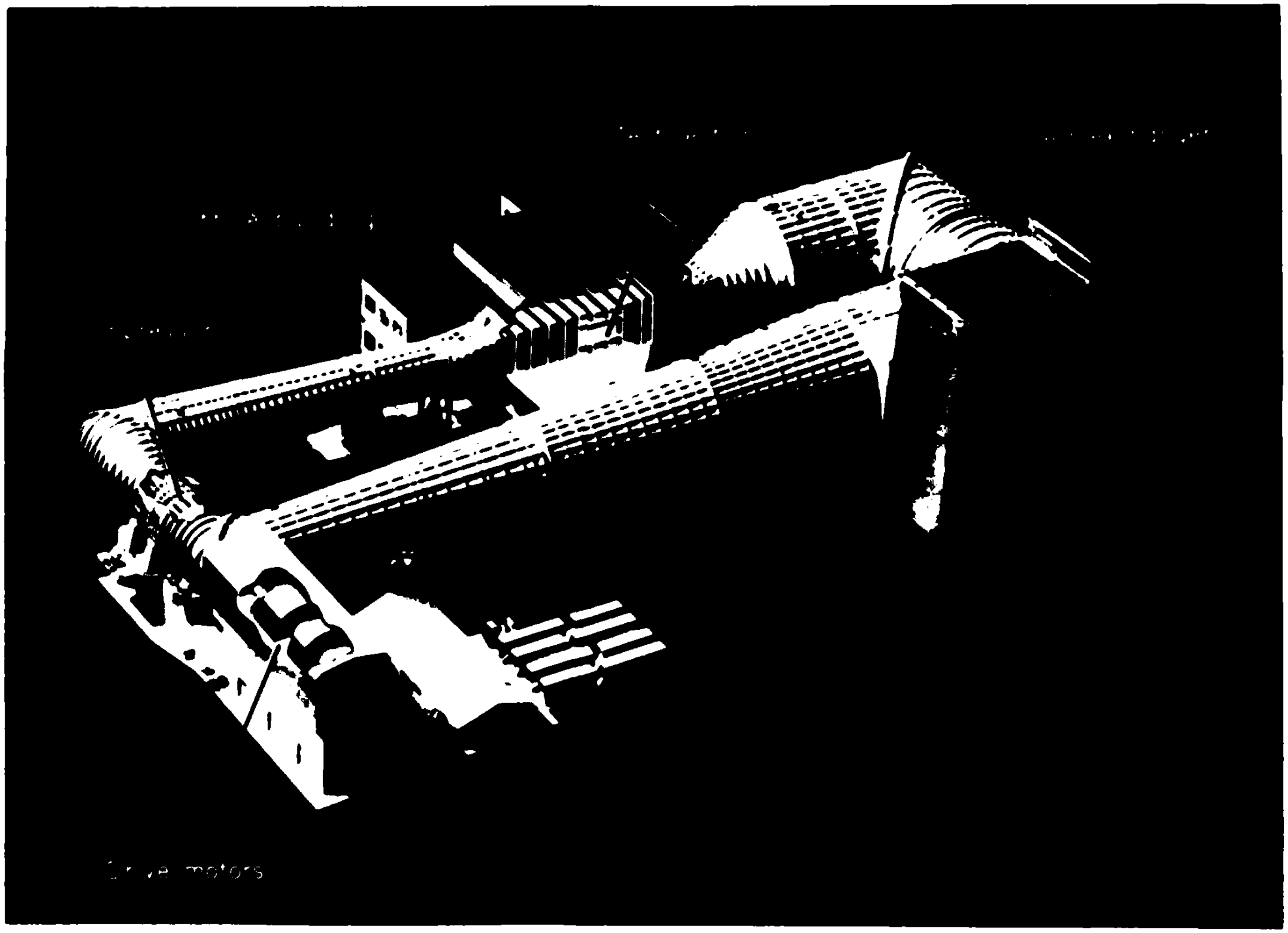


Figure 1.- The Ames 14-foot transonic wind tunnel.

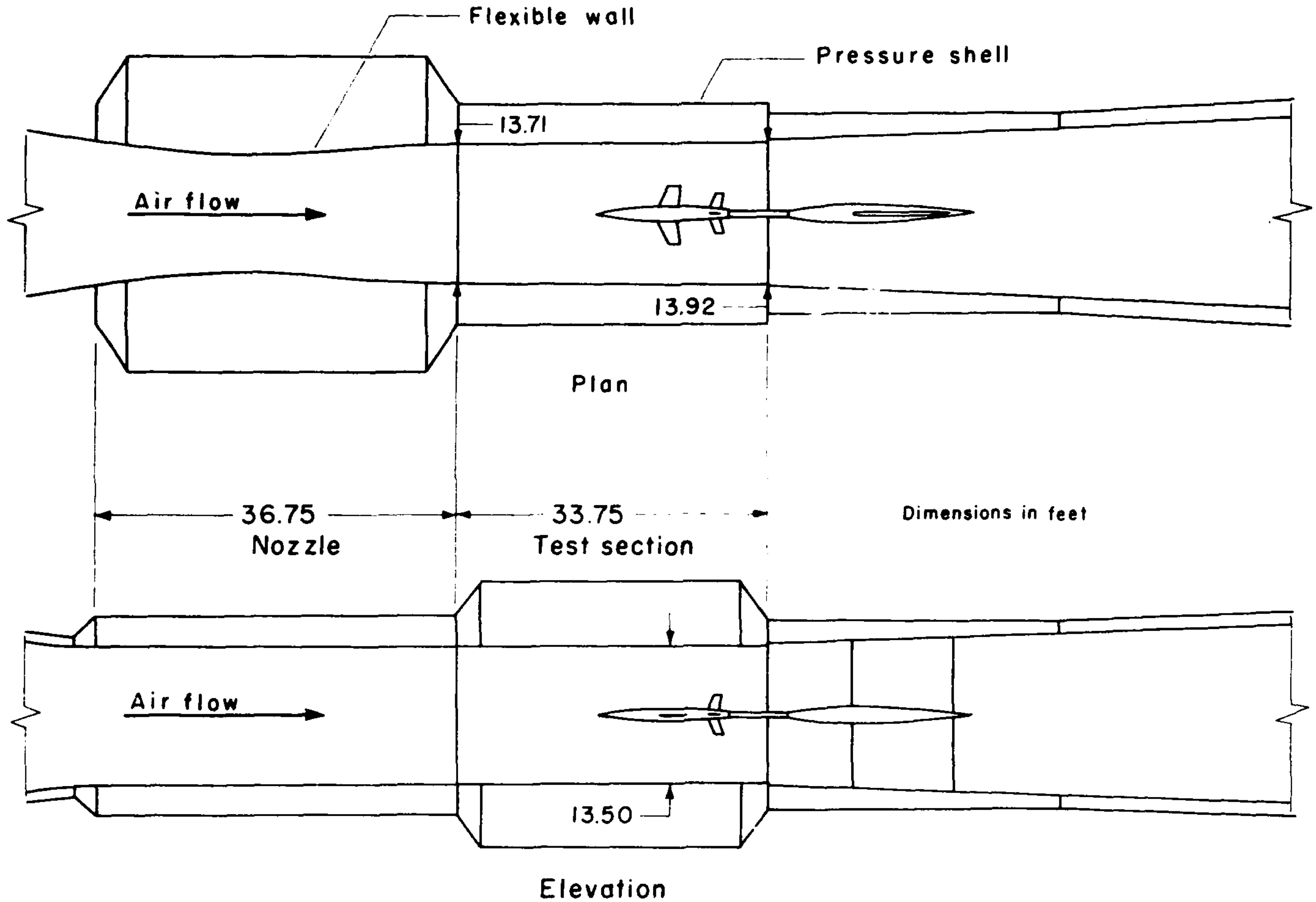


Figure 2.- The nozzle, test section, and model support for the Ames 14-foot transonic wind tunnel.

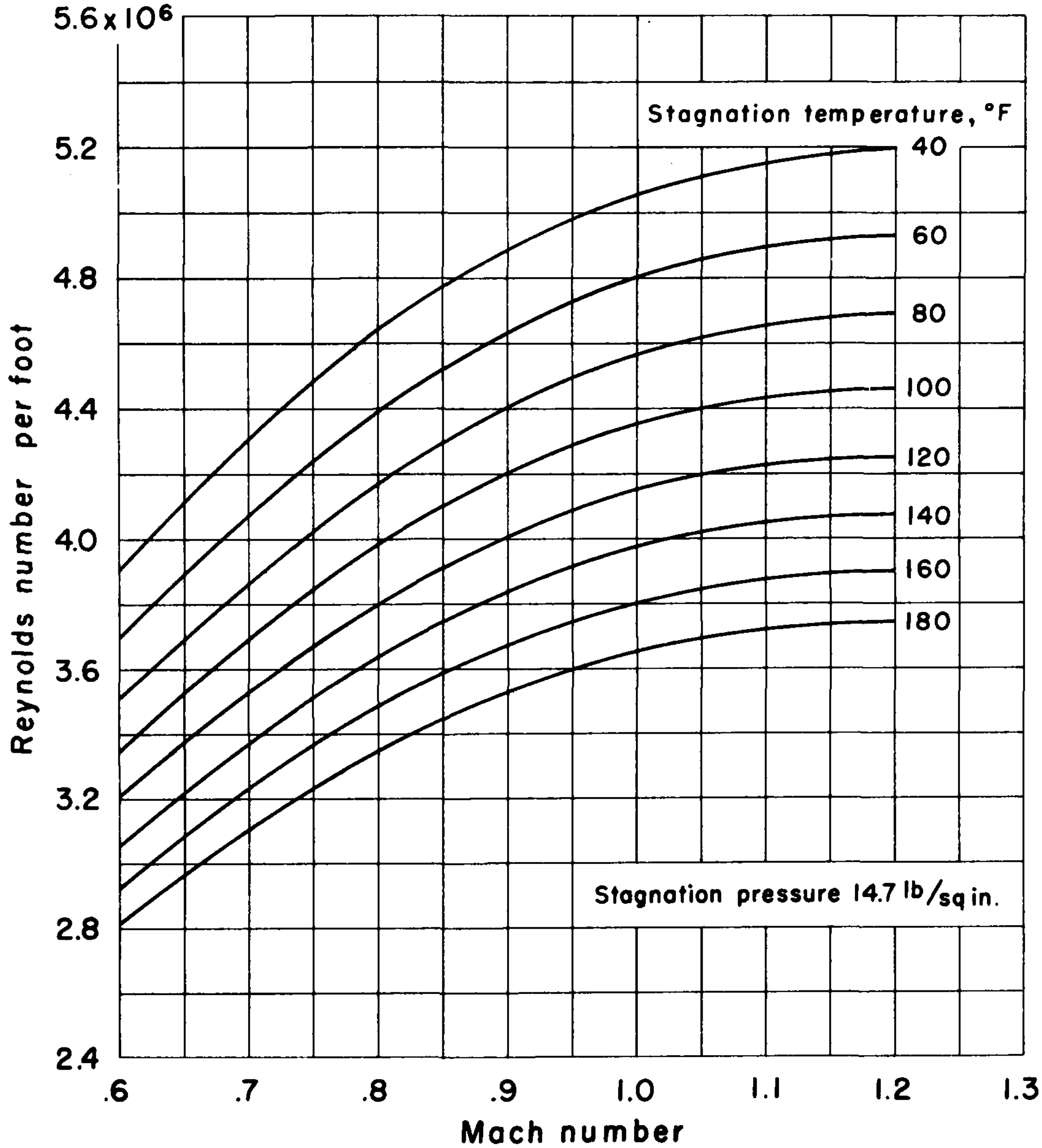


Figure 3.- Variation of Reynolds number with Mach number for the Ames 14-foot transonic wind tunnel.

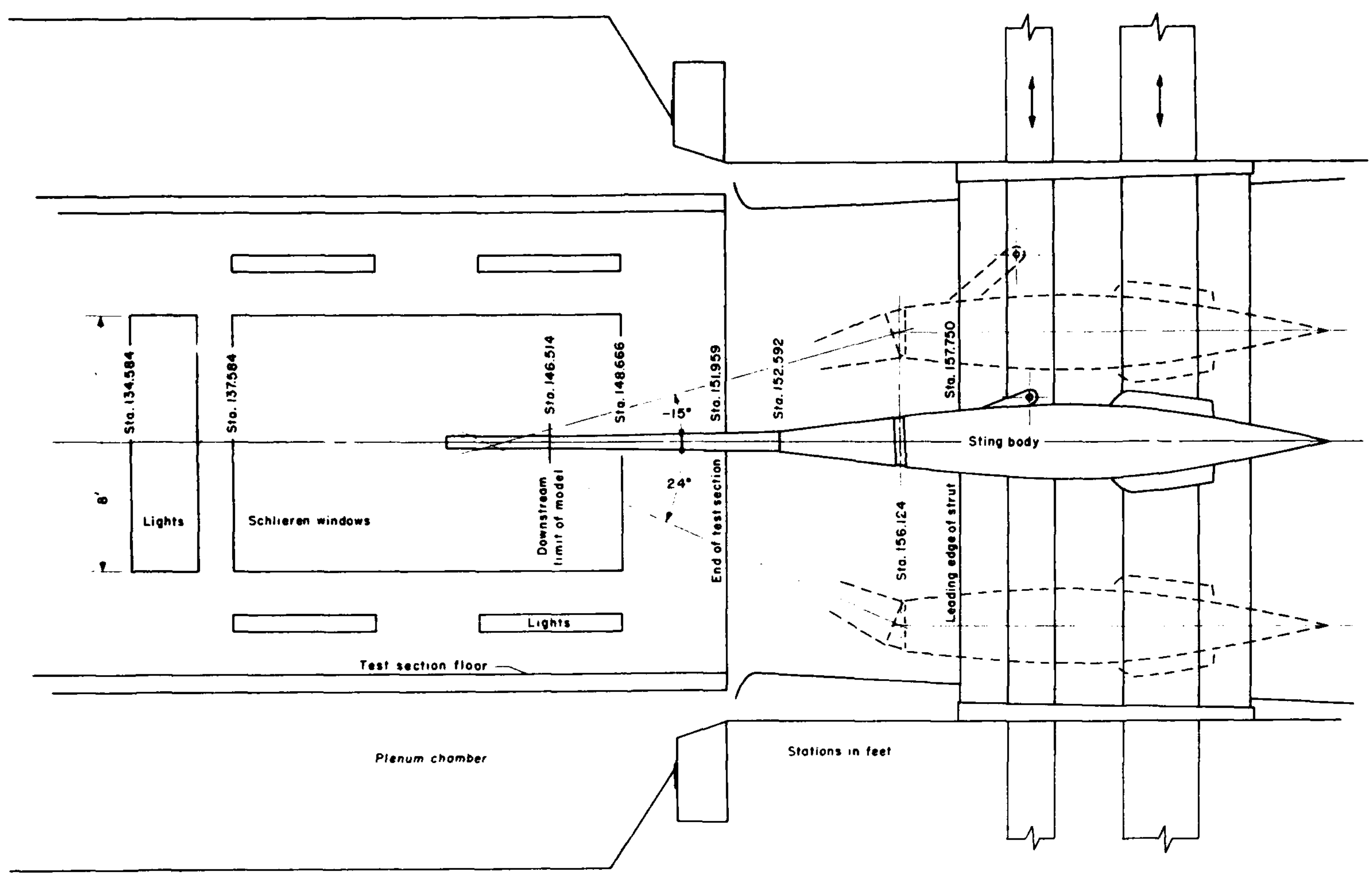


Figure 4.- Dimensions of the test section of the 14-foot transonic wind tunnel.

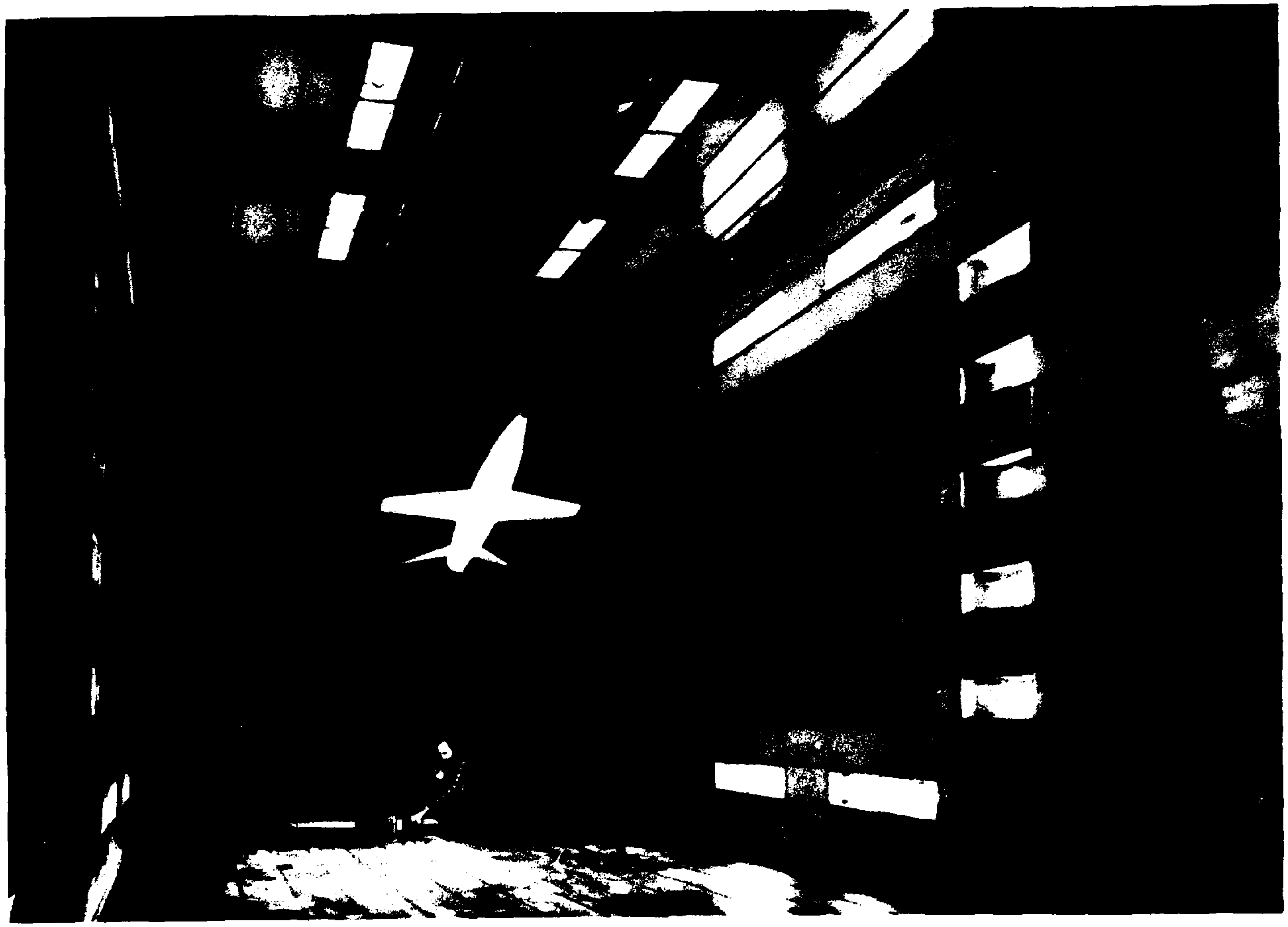


Figure 5.- Typical model in Ames 14-foot transonic wind tunnel.

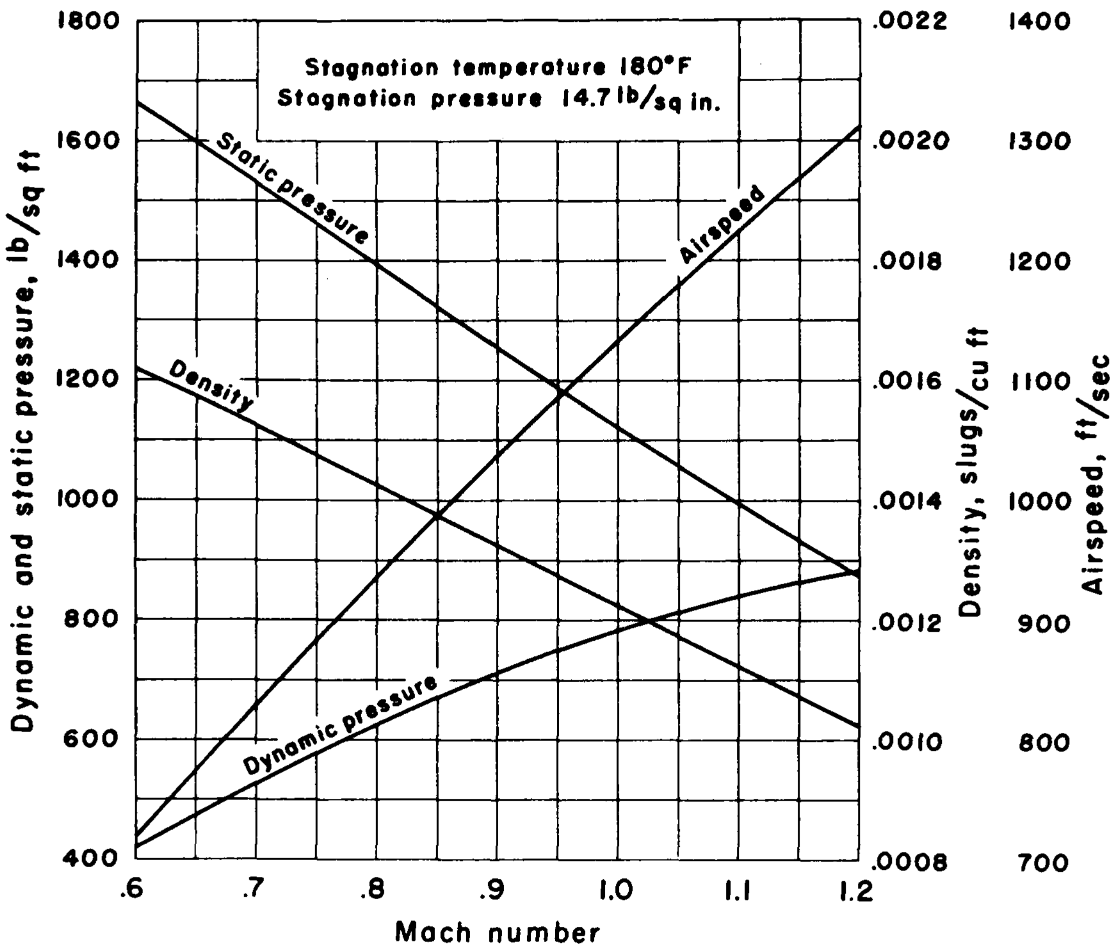


Figure 6.- Static and dynamic pressure, density, and airspeed in the test section of the Ames 14-foot transonic wind tunnel.

THE AMES
12- FOOT PRESSURE WIND TUNNEL

12-FT PRESSURE

Ames Aeronautical Laboratory

Moffett Field, California

NACA

AMES 12-FOOT PRESSURE WIND TUNNEL

GENERAL DESCRIPTION

The Ames 12-foot pressure wind tunnel is a variable-density, low-turbulence wind tunnel that operates at subsonic speeds up to slightly less than a Mach number of 1.0. This wind tunnel can be operated at any internal stagnation pressure from 2.5 to 75 pounds per square inch absolute. The general arrangement of the wind tunnel and associated equipment is illustrated in figure 1. The wind tunnel is powered by a two-stage, axial-flow fan driven by electric motors totaling 12,000 horsepower. Airspeed in the test section is controlled by variation of the rotative speed of the fan. The diameter of the settling chamber upstream from the test section is 60 feet, providing a contraction ratio of 25 to 1. Eight fine-mesh screens in the settling chamber, together with the large contraction ratio, provide an air stream of exceptionally low turbulence.

Access to the wind tunnel is through an air lock and balance chamber. The wind tunnel is entered only when the pressure is near atmospheric and no facilities are available for use of the air lock at other air pressures.

TEST SECTION

The test section is circular in cross section except for flat fairings. Figure 2 shows the dimensions and general arrangement of the test section.

TEST CONDITIONS

Mach number	0 to 0.98 continuously variable (See fig. 3.)
Pressure, stagnation	2.5 to 75.0 lb/sq in. abs
Reynolds number	0 to 9.5×10^6 per ft (See fig. 3.)
Temperature, stagnation	40° to 180° F. Generally above 100° F, depending on power being used.

MODEL-SUPPORT SYSTEMS

Sting Model Support

The location and general arrangement of the sting-type model support are shown in figure 2. A typical model installation is shown in figure 4. As illustrated, the sting-type model support consists of a fixed strut

mounted vertically in the wind tunnel to which is attached a movable body of revolution carrying the sting and, in turn, the model. The strut functions as a support and guide for the body of revolution which can be pitched in a vertical plane by means of motor-driven lead screws. The range of pitch angle is from -10° to $+20^{\circ}$. The same range of angles of sideslip may be obtained after manually rotating the model 90°. This system provides variation in either pitch or sideslip but not both simultaneously. The range of either variable or the magnitude of the parameter being held constant can be changed by the use of bent stings.

For preliminary planning, the load capacity of the sting-type model support shall be assumed to be that corresponding to moments at the front lead screw of +46,000 and -23,000 pound feet in the plane of the vertical strut and ±8,000 pound feet at right angles to the plane of the vertical strut. The front lead screw is at station 132.29 feet while the sting-balance center is typically at station 124.53 feet.

A ground plane is available for use with sting-mounted models for simulation of airplane characteristics near the ground. A typical installation with this ground board is shown in figure 5.

Semispan Model Support

The location and general arrangement of the semispan-type model support are shown in figure 2. A typical model installation is shown in figure 6. The model is mounted on the floor of the wind tunnel on a turntable 46 inches in diameter. The turntable is supported on a balance frame which, in turn, rests on a scale system. The angle-of-attack range is either -20° to $+20^{\circ}$ or -10° to $+30^{\circ}$. However, it should be noted that if a half-fuselage is used, the angle-of-attack range may be limited by the width of the flat fairing (see fig. 2).

The allowable loads for the semispan model support are as follows:

Lift	±2800 lb
Drag	+3000 and -1000 lb
Pitching moment about center of rotation	±6000 lb-ft

Through-Model Support

A through-model-support system is provided whereby models spanning the test section may be tested (see fig. 2). A typical model installation is shown in figure 7. Models are mounted on 36-inch-diameter turntables that are flush with the tunnel-wall fairings. These turntables are supported on a balance frame which transmits forces to the same scales system used for the semispan model support. The angle-of-attack range is from -10° to $+30^{\circ}$.

The allowable loads for the through-model support are as follows:

Lift	+20,000 and -4,000 lb
Drag	+3,000 and -1,000 lb
Pitching moment about center of rotation	±12,000 lb-ft

Propeller Dynamometer

The propeller dynamometer has a rating of 1000 horsepower at 6600 revolutions per minute. The equipment is illustrated in the photographs in figure 8 and has been described in detail in NACA RM A52I19a.

MODELS

Typical models mounted on the various model supports have been presented in figures 4 through 8. Only very general model requirements will be stated here. It is essential that the wind-tunnel staff be consulted early during the planning of any investigation to assure that the latest of the continuously evolving techniques and equipment will be used to best advantage. Details of mounting dimensions, of available balances, and of other equipment and instruments can be supplied at the time of such consultation. The optimum size of a model depends on the purpose of the investigation and shall be determined by consultation.

The model structure and the mechanisms and instrumentation within the model must function reliably over the following range of environment in the test section: stagnation temperatures from 30° F to 180° F; humidity below 0.0004 of a pound of water per pound of air; and stagnation pressures and dynamic pressures as denoted in figure 3.

INSTRUMENTATION

Balances

For the sting type of model support the over-all steady-state forces and moments acting on models are measured by strain-gage balances. These balances are installed in the models and mounted on the end of the supporting sting. A 2.5-inch-diameter, six-component balance with a lift capacity of 2800 pounds and a 4.0-inch-diameter four-component balance with a lift capacity of 3300 pounds are generally used in this wind tunnel. Details of balances available at the Laboratory can be supplied by consultation with the wind-tunnel staff.

Forces and moments on components such as control surfaces are usually measured by strain-gage devices designed as part of each model. The strain gages should be designed in accordance with specifications which can be obtained from the Laboratory to insure compatibility with the recording equipment.

The Laboratory has some special equipment for the measurement of dynamic stability derivatives.

Manometers

Facilities are installed to accommodate four 82-tube manometers that can be photographed simultaneously. Present equipment includes one manometer containing mercury, four containing tetrabromoethane, and four containing water. These manometers have a usable height of 54 inches and scales with 0.1-inch divisions. A 64-tube, 10-foot, integrating water manometer is also available. Other pressure-measuring devices are available when higher sensitivity is required.

Pressure fluctuations can be measured and recorded with special equipment at the Laboratory. Arrangements for installation and use of this equipment must be made by consultation with the wind-tunnel staff.

Data Recording and Reduction

Forces and moments.- Data are recorded by printing devices, they are computed manually or, for large lots of data, are transferred manually to punched cards and the coefficients are computed by machine at the Laboratory's computing center.

Pressures.- Pressures are recorded by photographing multiple-tube manometers. The photographs are read manually with a special device which automatically computes the coefficients and lists them in numerical form.

Flow Visualization

There are no facilities for schlieren or shadowgraph visualization of flow. The only provisions for observation of the model are through three 5-inch-diameter ports in the access hatch in the top of the balance chamber, and through a viewing telescope. The viewing telescope has a limited field of vision (see fig. 2) and only the rear portion of a sting-mounted model can be seen. However, the test section is provided with mercury-vapor lighting, and motion pictures of a model can be taken by remotely operated cameras mounted in the balance chamber.

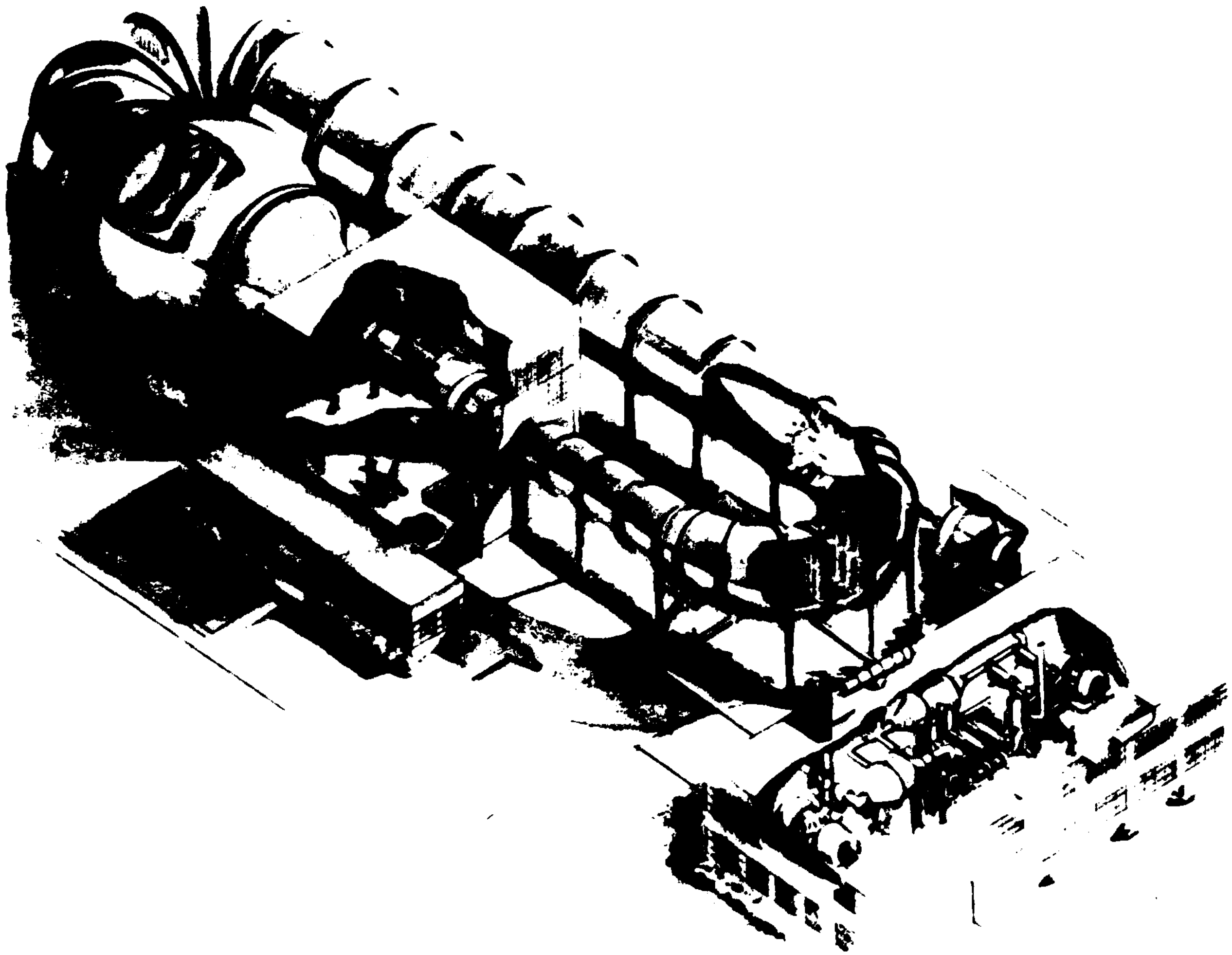


Figure 1.- The Ames 12-foot pressure wind tunnel.

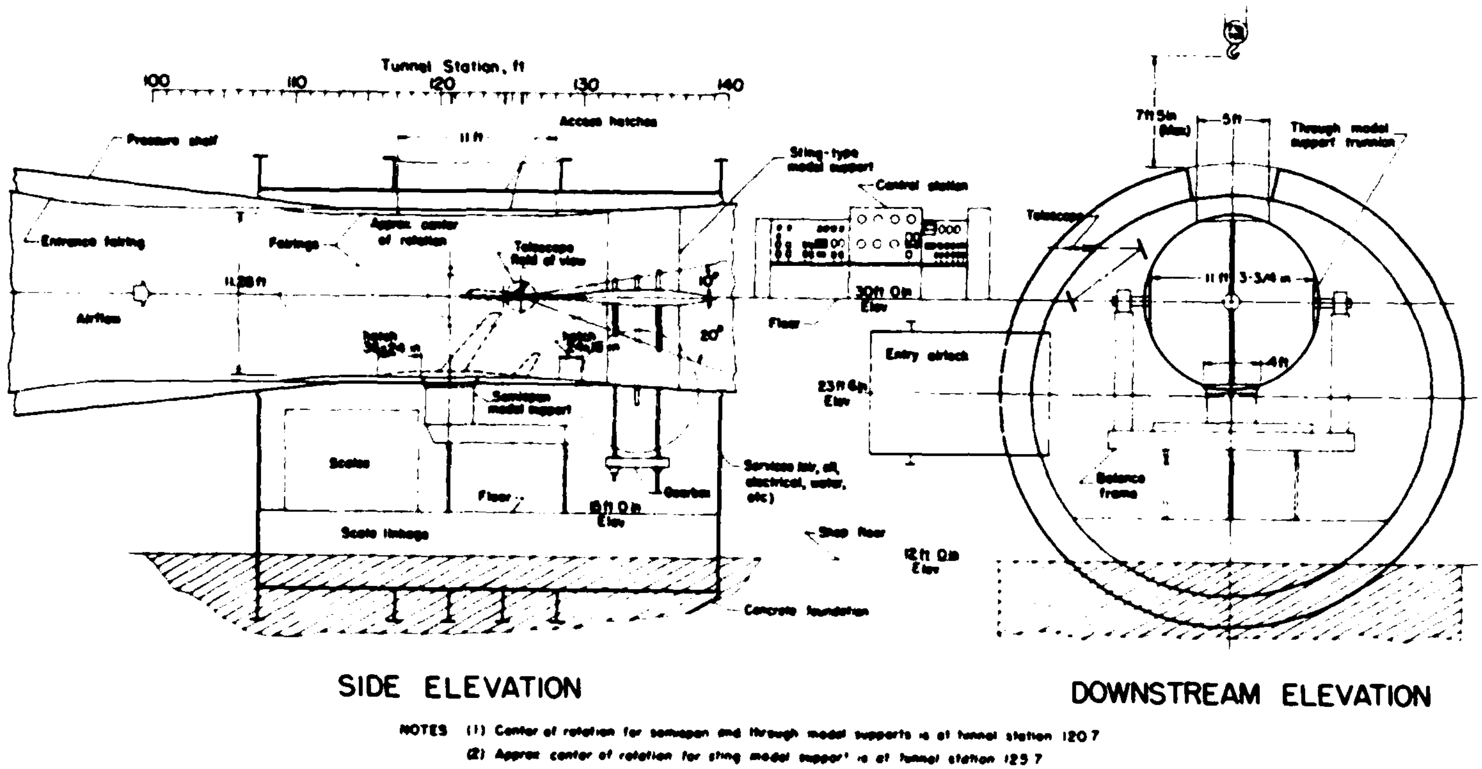


Figure 2.- General arrangement of the test section and balance chamber of the Ames 12-foot pressure wind tunnel.

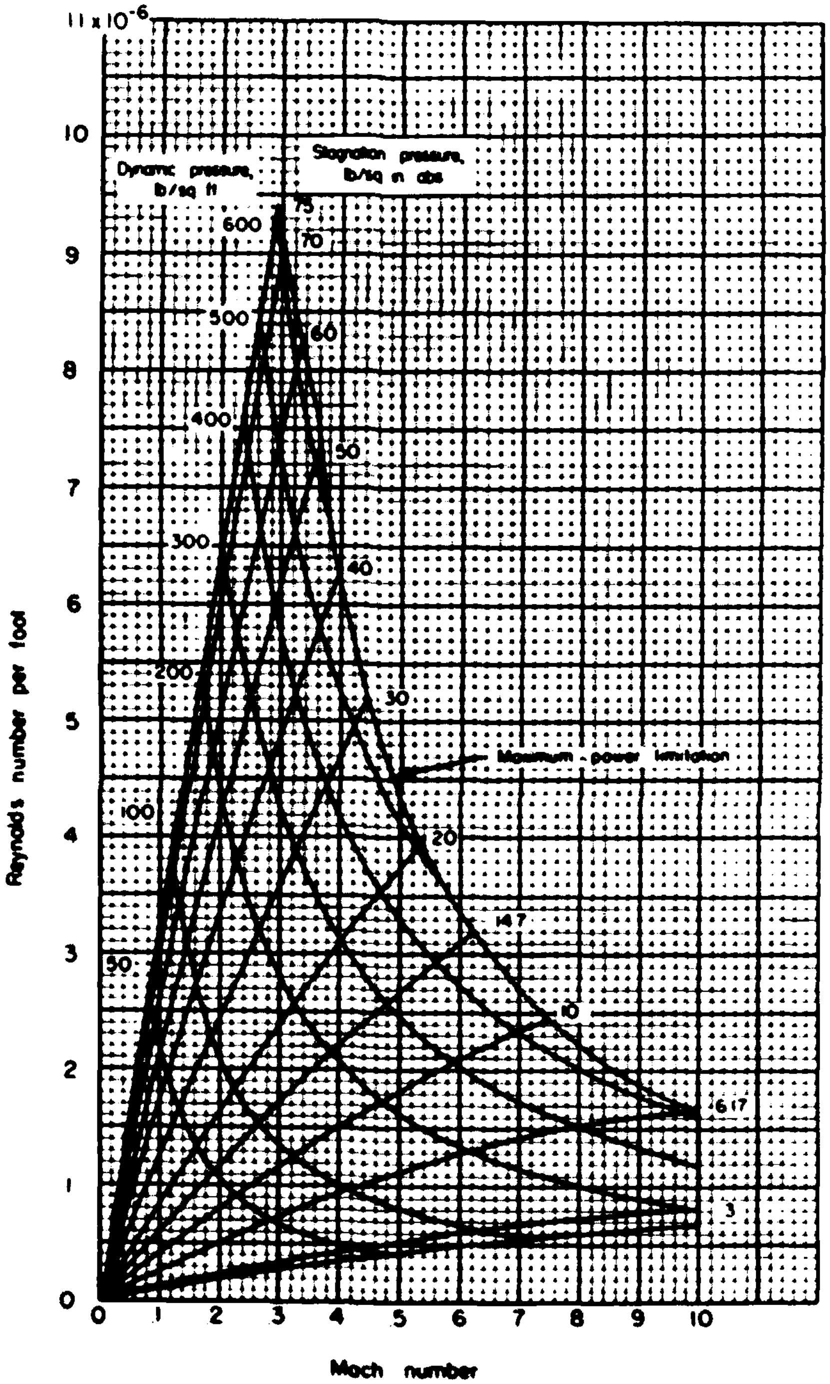


Figure 3.- Operating characteristics of the Ames 12-foot pressure wind tunnel.

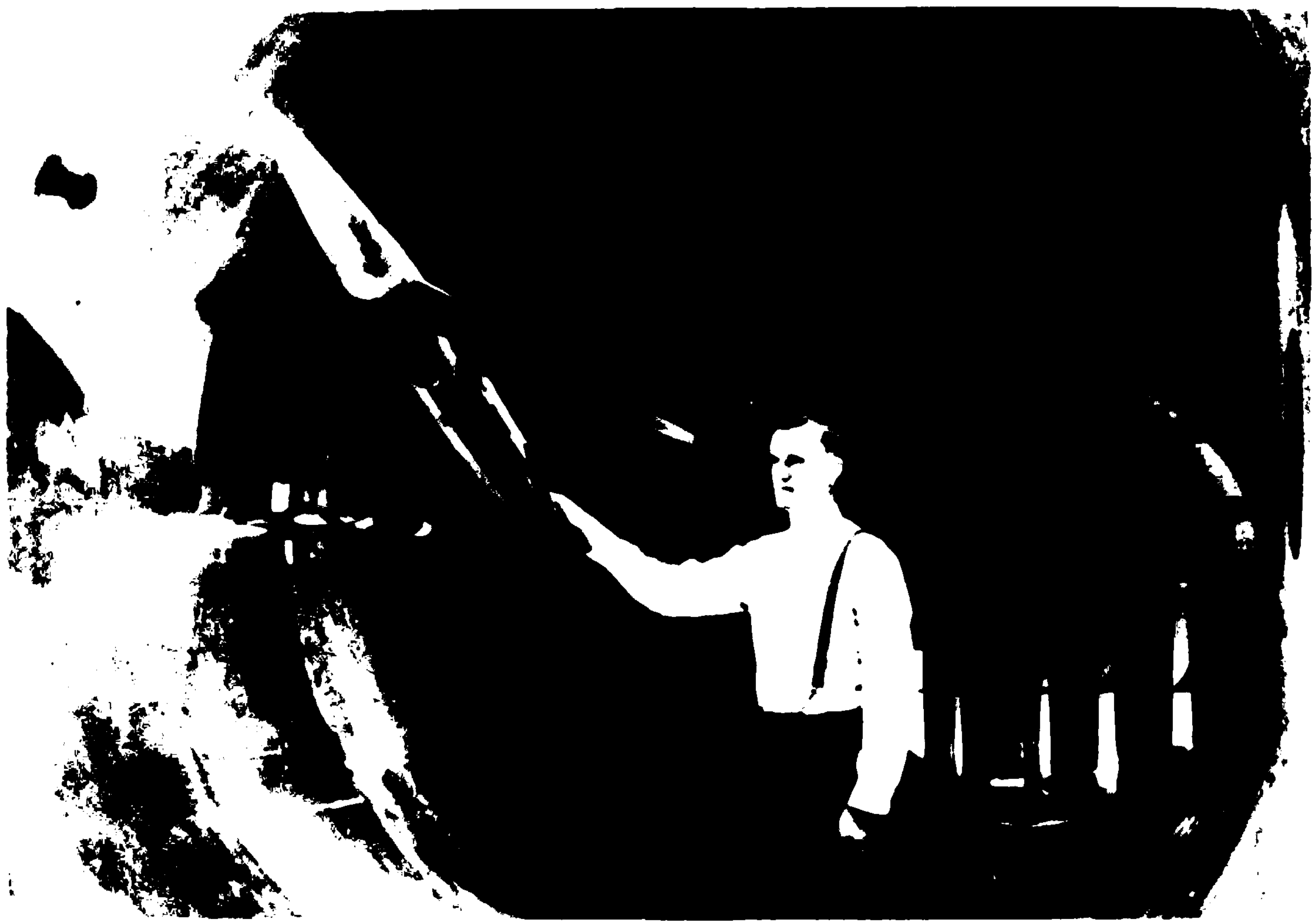


Figure 4.- Typical model installation on the sting-type support in the Ames 12-foot pressure wind tunnel.

Figure 5.- Ground plane for simulation of airplane landing conditions in the Ames 12-foot pressure wind tunnel.

Figure 6.- Typical semispan model installation in the Ames 12-foot pressure wind tunnel.

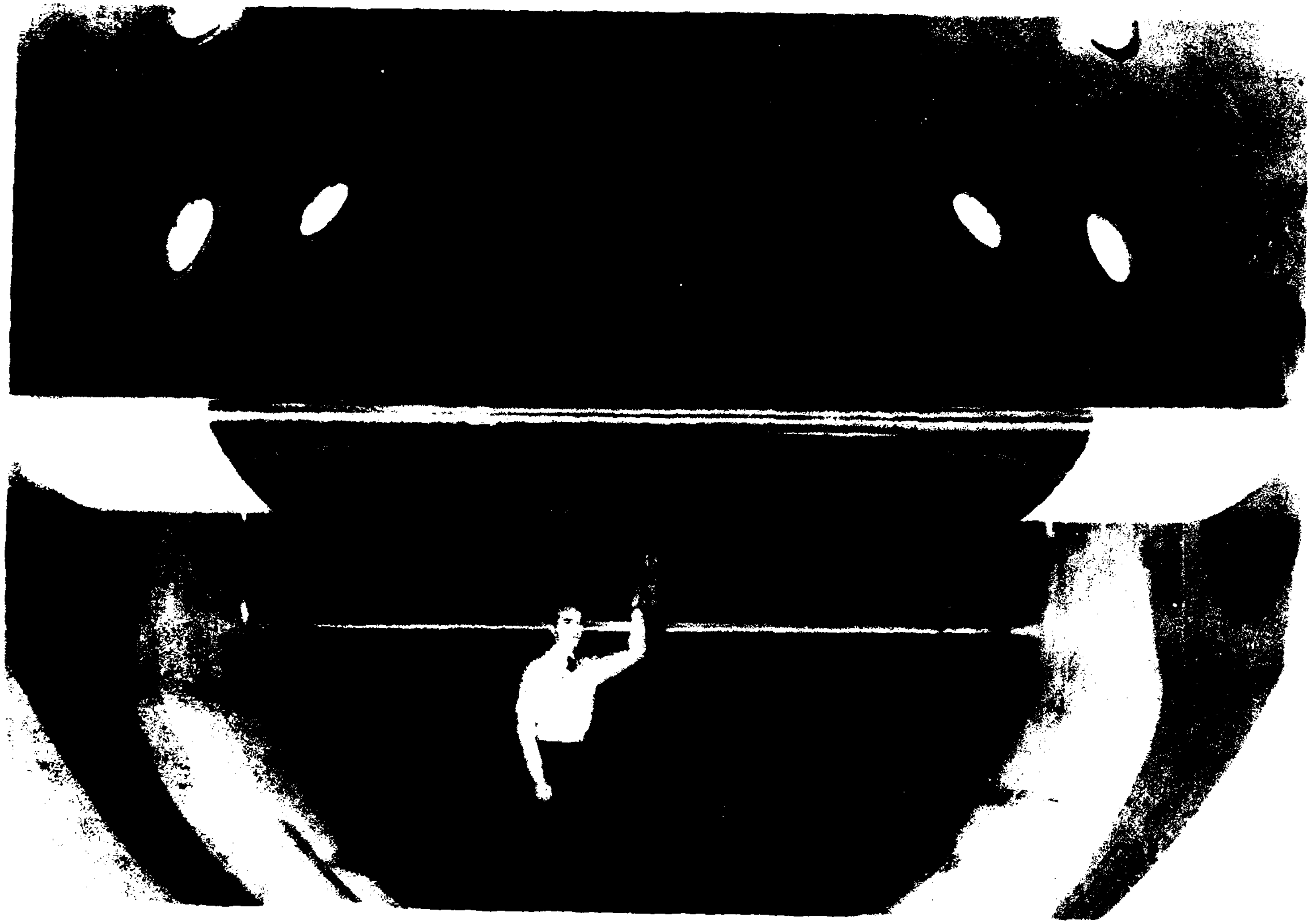
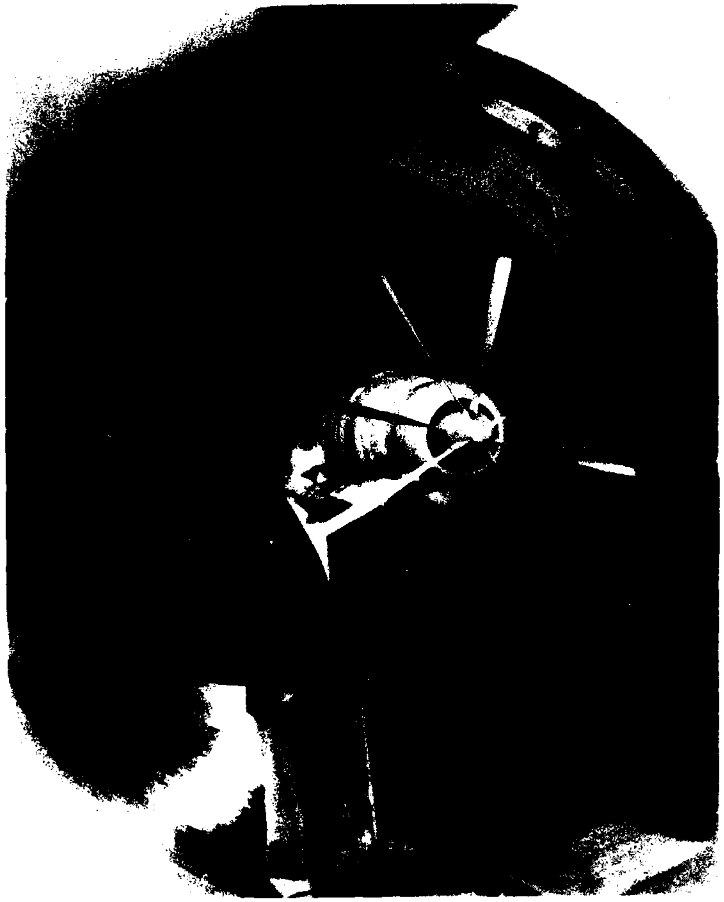


Figure 7.- Typical model installation on the through-model support in the Ames 12-foot pressure wind tunnel.

(a) Single-rotation propeller.



(b) Dual-rotation propeller with cowl.

Figure 8.- One-thousand-horsepower propeller dynamometer in the Ames 12-foot pressure wind tunnel.

THE AMES
6- BY 6- FOOT SUPERSONIC WIND TUNNEL

Ames Aeronautical Laboratory
Moffett Field, California

6- BY 6-FT
SUPERSONIC

AMES 6- BY 6-FOOT SUPERSONIC WIND TUNNEL

GENERAL DESCRIPTION

The Ames 6- by 6-foot supersonic wind tunnel is of the closed-circuit, single-return type. It has an asymmetric, sliding-block nozzle and a test section with perforated floor and ceiling for removal of the boundary layer on these surfaces. Aftercooling is provided to limit the maximum stagnation temperature. A drawing of the facility is shown in figure 1 and the general arrangement of the test chamber is shown in figure 2. Pertinent dimensions of the test section and model support system are shown in figure 3. The air is driven by an eight-stage, axial-flow compressor which is powered by two electric motors mounted in tandem outside the wind tunnel. The drive system is rated at 60,000 horsepower.

TEST SECTION

The test section, as shown in figure 3, is approximately 6 feet square in cross section and is 14 feet 5 inches long. The floor and ceiling are now perforated to prevent choking at transonic speeds, to minimize shock reflection, and to minimize any air-stream angularity that might result from the asymmetric nozzle.

TEST CONDITIONS

Mach number	0.6 to 2.25, continuously variable
Pressure, stagnation	Variable from approximately 4 to approximately 16 lb/sq in. abs (See fig. 4.)
Reynolds number	Variable over the range shown in figure 4
Temperature, stagnation	Maximum approximately 115° F

MODEL-SUPPORT SYSTEM

Models are supported from the rear by stings projecting from the sting-support body which is mounted on the vertical strut downstream of the test section (fig. 3). The sting-support body is positioned by two lead screws attached to the top of the push rods shown in figure 3. The rear push rod moves at 9/7 the rate of the forward rod. The elevation of the support body above the tunnel floor can be adjusted at the initial alinement of the push rods for a given model installation. The model angle of attack can be varied from 18° nose-down to 13° nose-up by the differential motion. Bent stings can be used to shift this operating range in either direction, the amount possible depending on the model size

and other factors. Also, the total angle range can be increased, if necessary, by changing stings during an investigation. In order to conserve wind-tunnel time, such changes should be avoided. Sideslip angles of $\pm 5^{\circ}$ and $\pm 10^{\circ}$ can be obtained throughout the angle-of-attack range by the use of the bent stings currently available. Mounting the model with its wing span vertical (the angle of sideslip is then varied by the same mechanism that normally varies the angle of attack) provides the same range of sideslip angles as angles of attack. By use of the bent stings the angle of attack can then be set at $\pm 5^{\circ}$ or $\pm 10^{\circ}$.

MODELS

A typical model mounted in the test section is shown in figure 5. Only very general model requirements will be stated here. It is essential that the wind-tunnel staff be consulted early during the planning of any investigation to assure that the latest of the continuously evolving techniques and equipment will be used to best advantage. Details of mounting dimensions of available balances and of other equipment and instruments can be supplied at the time of such consultation. The optimum size of the model depends on the purpose of the investigation and shall be determined by consultation. At the present time the following are generally recommended as maximums:

Frontal area	0.2 sq ft
Body length	60 in.
Wing span	3 ft

The model structure and the mechanisms and instrumentation within the model must function reliably over the following range of environment in the test section: stagnation temperatures which may change rapidly from as low as 30° F to approximately 115° F as the wind tunnel is brought up to speed; extremely low humidity; and the static pressures and dynamic pressures which are shown in figure 4.

INSTRUMENTATION

Balances

The over-all steady-state forces and moments acting on models are measured by strain-gage balances mounted on the end of the supporting sting within the model. Balances 1-1/2, 2, and 2-1/2 inches in diameter with total lift capacities of 1000, 1800, and 2800 pounds, respectively, are generally used in this wind tunnel. Details of balances available at the Laboratory can be ascertained by consultation with the wind-tunnel staff. Forces and moments on components such as control surfaces are usually measured by strain-gage devices designed as part of each model. The strain gages should be designed in accordance with specifications

which can be obtained from the Laboratory to insure compatibility with the recording equipment. The Laboratory has some special equipment for the measurement of dynamic stability derivatives.

Manometers

Six 82-tube manometers are available with a usable height of 60 inches and scales having 1/10-inch least divisions. Two 62-tube manometers with a usable height of 84 inches with scales having 1/10-inch least divisions are also available. Mercury, tetrabromoethane, and dibutylthalate are used for manometer fluids. Recording of manometer readings is done by photography. More manometers can generally be provided when needed. Pressure fluctuations can be measured and recorded with special equipment at the Laboratory. Arrangements for installation and use of this equipment must be made by consultation with the wind-tunnel staff.

Data Recording and Reduction

An automatic data-reduction system is available for this wind tunnel. This equipment enables monitoring of both raw data and the computed results as the test progresses and provides tabulated and plotted data in coefficient form concurrent with operation of the wind tunnel. The system is shown schematically in figure 6. The equipment is capable of reading the outputs from eight channels of electrical-resistance strain gages. In the usual case six of these channels are used with a six-component strain-gage balance, leaving two components for other uses. In addition, equipment is available for recording six supplementary channels defining the model test conditions, such as angle of attack, angle of sideslip, Mach number, etc.; for recording 28 decades of miscellaneous information; and for digitizing and recording the outputs of four selsyn motors.

Several methods are available for reading photographs of the liquid-in-glass manometers and for computing the pressure coefficients. All these methods involve some manual operations. The method used depends on the circumstances involved in each case.

Flow Visualization

In each side of the test section are two pressure-tight glass windows (fig. 3). The upstream windows are used only for observation while the downstream windows are used for both direct visual observation and for schlieren visualization of the flow. (Generally, models will be in line with the downstream windows.) The clear area of the windows is 46 inches in diameter. Photographs of the patterns of density gradient can be made by means of the schlieren camera.

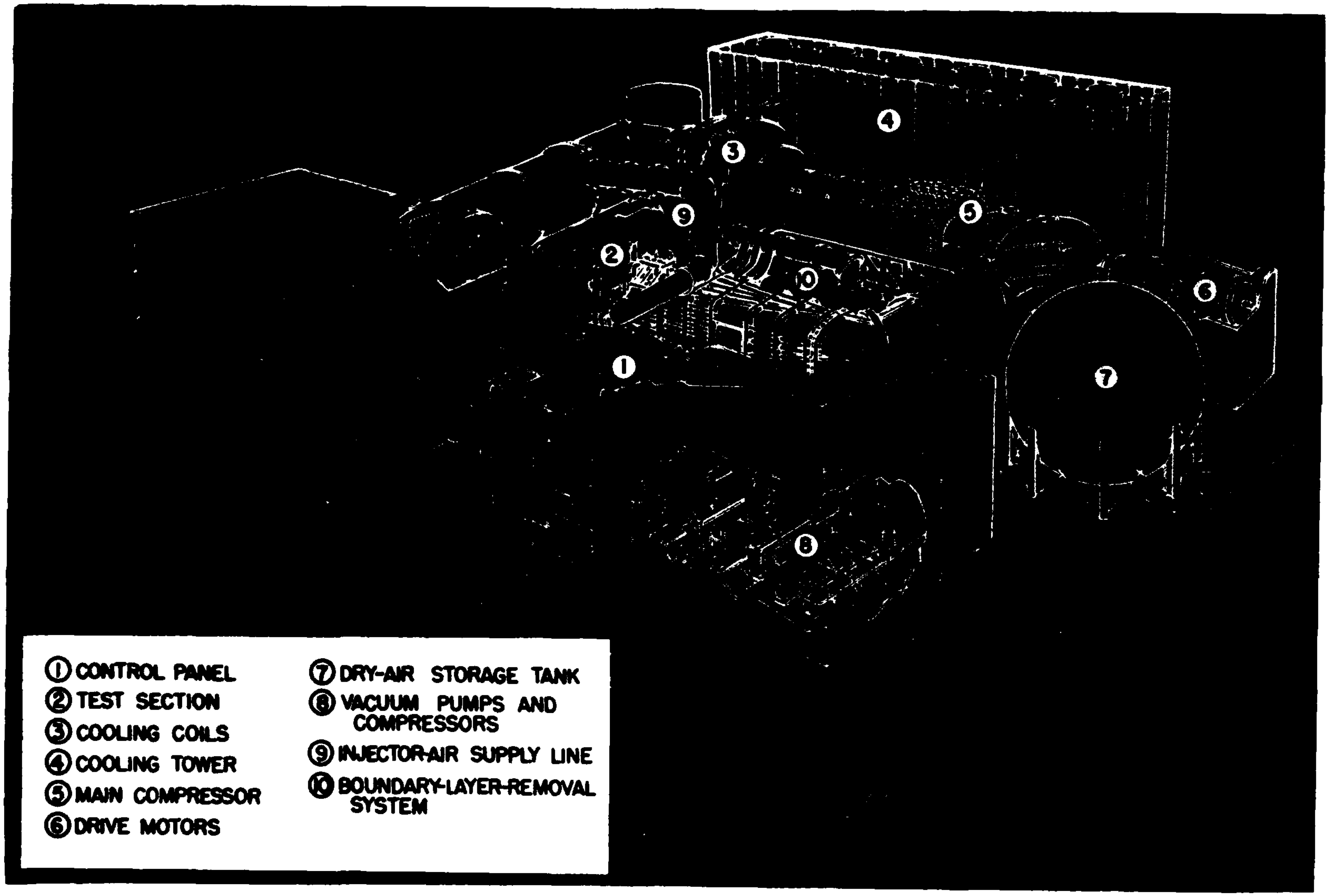


Figure 1.- The Ames 6- by 6-foot supersonic wind tunnel.

Figure 2.- General arrangement of the test chamber of the Ames 6- by 6-foot supersonic wind tunnel.

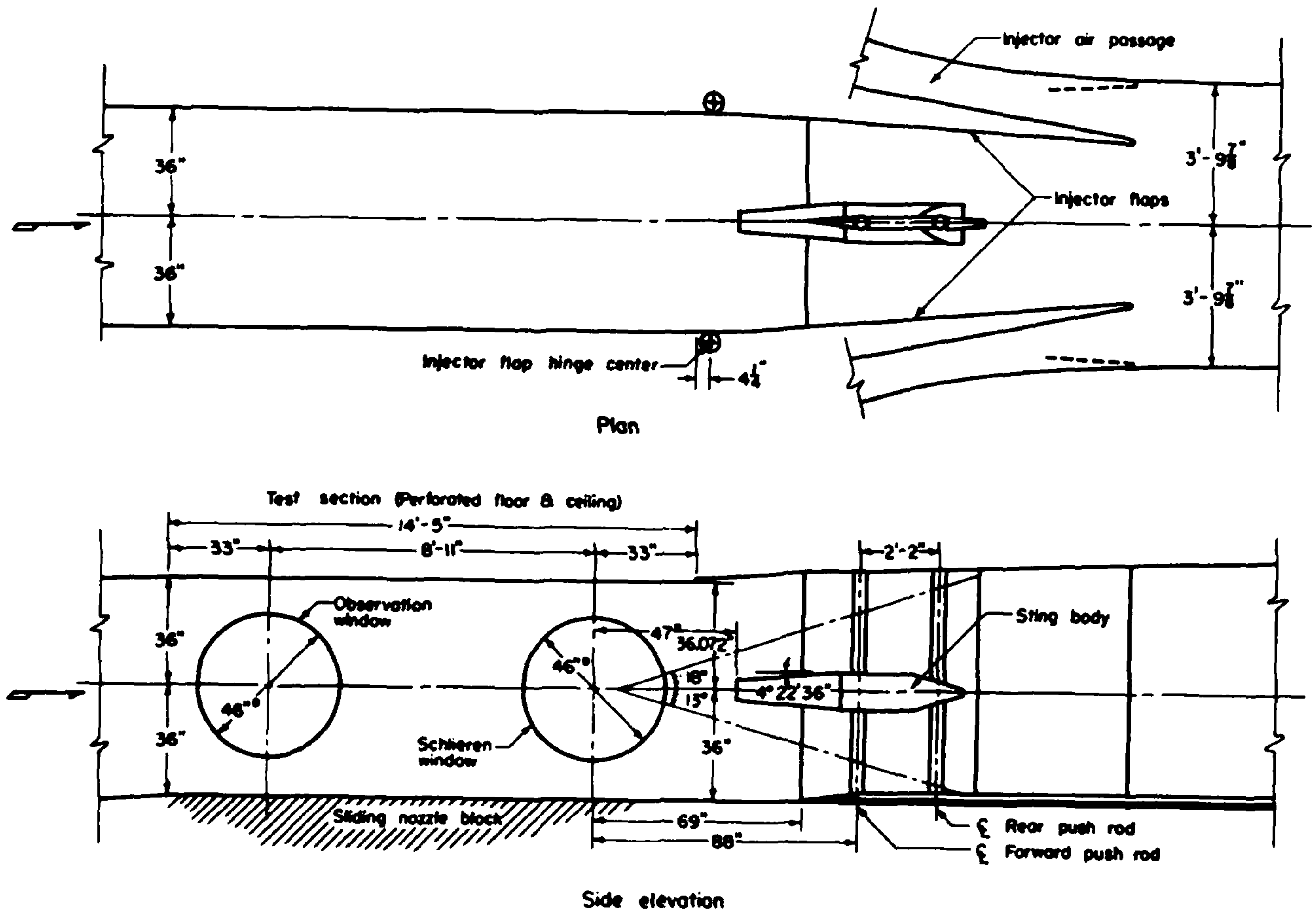


Figure 3.- Ames 6- by 6-foot supersonic wind tunnel test section and model-support system details.

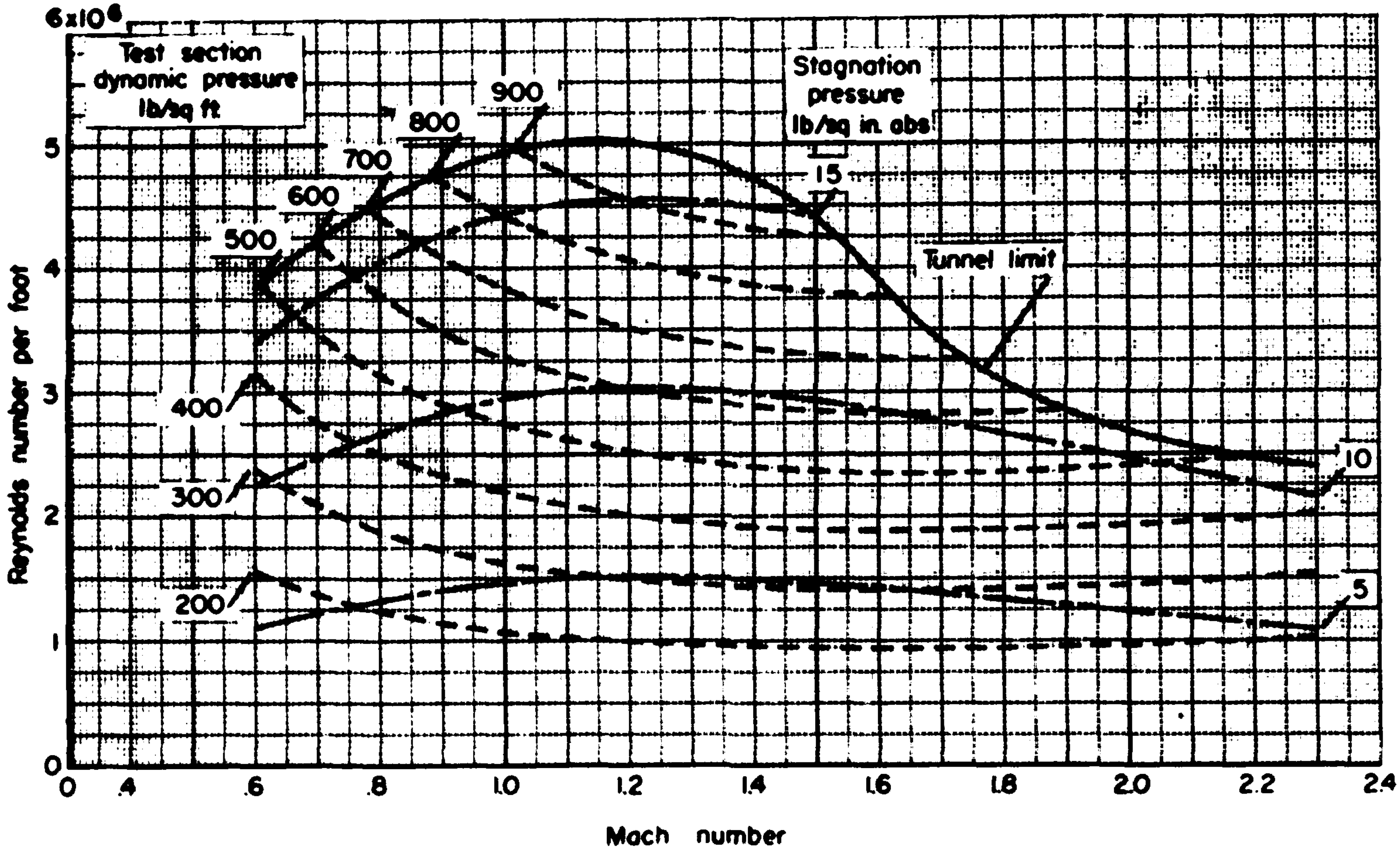


Figure 4.- Operating characteristics of the Ames 6- by 6-foot supersonic wind tunnel.
(Stagnation temperature of 100° F.)

Figure 5.- Typical model [illegible] Ames [illegible] supersonic wind tunnel.

1 Strain-gage leads
2 Strain-gage dial indication
3 Tabulation of strain-gage readings
4 Pressure tubes or wires from supplementary pick-ups
5 Ten channels of electrical signals from transmitting selsyns
6 28 decades of electrical signals from factor board
7 Digitized data from supplementary servos and factor board
8 Digitized data from 8-channel recorder, supplementary servos, and factor board
9 Tape punch. Tape contains aerodynamic coefficients plus scale factors and zero off-sets necessary for plotting
10 Tape reader to convert tape punches to electrical signals used to actuate plotter
11 Aerodynamic coefficients plus scale factors and zero off-sets
12 Tabulated aerodynamic coefficients
13 Digitized aerodynamic coefficients
14 Aerodynamic coefficients recorded in punched paper tape

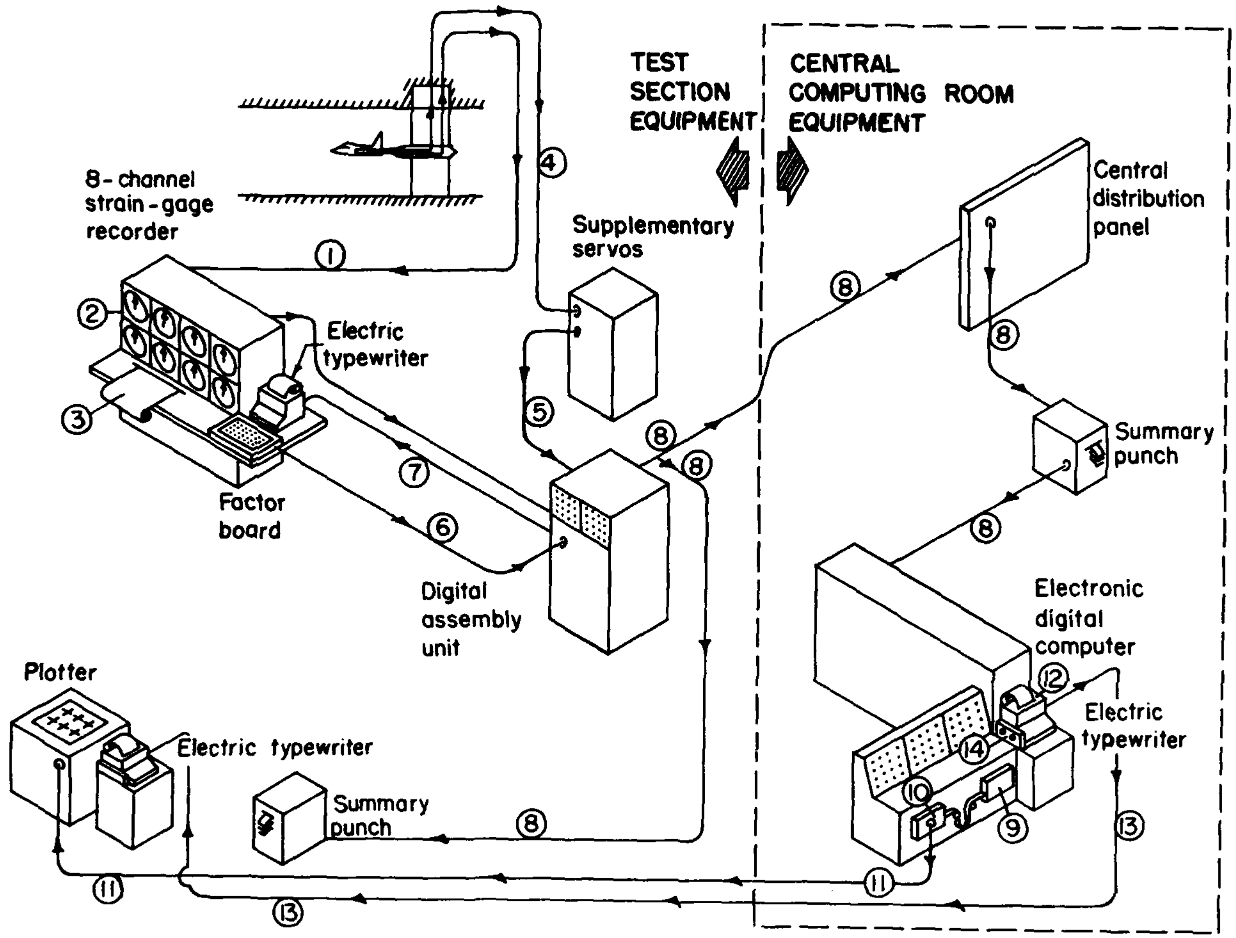


Figure 6.- Data processing system for Ames 6- by 6-foot supersonic wind tunnel.

THE AMES
2- BY 2- BY FOOT TRANSONIC
WIND TUNNEL

Ames Aeronautical Laboratory

Moffett Field, California

2- BY 2-FT
TRANSONIC

NACA

AMES 2- BY 2-FOOT TRANSONIC WIND TUNNEL

GENERAL DESCRIPTION

The Ames 2- by 2-foot transonic wind tunnel is of the closed return, variable-density type. A flexible-wall nozzle is situated upstream of the test section. The tunnel drive system is comprised of a two-stage, axial-flow compressor driven by four 1000-horsepower water-cooled induction motors. A drawing of the building floor plan and tunnel circuit is shown in figure 1 and a sectional perspective view of the nozzle and test section is shown in figure 2.

TEST SECTION

The test section is 2 feet square in cross section and 58 inches long. The walls of the test section are perforated to prevent choking and to alleviate the reflection of shock waves. It is surrounded by a pressure-tight chamber.

TEST CONDITIONS

Mach number	0 to 1.4, continuously variable
Pressure, stagnation	5 to 35 lb/sq in. abs
Reynolds number	4.8×10^6 to 8.7×10^6 per ft (See fig. 3.)
Temperature, stagnation	70° F to 120° F
Humidity	about 0.0003 lb of water per lb of air

MODEL-SUPPORT SYSTEM

Access to the test section for model installation is accomplished by removing the test-section pressure chamber and swinging aside either or both of the perforated test-section side walls. The models are installed on a sting-mounted internal strain-gage balance. A top view of the test region showing the support system is presented in figure 4. Variation of angle of attack occurs in a horizontal plane with the center of rotation on the test-section center line. The angle-of-attack range is from -8° to $+8^\circ$ with a straight sting. This range may be altered by the use of bent stings with the angle of bend in the plane of pitch (i.e., the horizontal plane). Stings with bend angles up to 16° are available.

Variation of angle of sideslip from -8° to $+8^\circ$ is also accomplished in the horizontal plane. For the sideslip tests, the bent stings are installed with the angle of bend in the vertical plane to produce fixed angles of attack.

Only very general model requirements will be stated here. It is essential that the wind-tunnel staff be consulted early during the planning of any investigation to assure that the latest of the continuously evolving techniques and equipment will be used to best advantage. Details of mounting dimensions, available balances, and other equipment and instruments can be supplied at the time of such consultation.

The optimum size of a model depends on the purpose of the investigation and shall be determined by consultation. At the present time, the following are generally recommended as maximums:

Frontal area	0.02 sq ft
Length	1.5 ft
Span	1.0 ft

All items supplied by the contractor such as models, balances, stings, etc., shall be capable of satisfactory performance in the wind-tunnel environment. Since prior to operation the wind tunnel is purged to nearly zero pressure and filled with dry air at the desired test pressure (35 lb/sq in. abs maximum), materials which absorb or release moisture or air shall not be used in the construction of any item. Further, all equipment shall be capable of satisfactory performance at temperatures from 70° F to 120° F.

INSTRUMENTATION

Balances

Internal strain-gage balances are used because only the sting-type support is available. The balances generally have a nominal diameter of 1 inch and a maximum normal-force capacity of 280 pounds.

Manometers

Two 80-tube, 60-inch-high manometers are available. Normally, one is filled with mercury and the other with tetrabromoethane. Both manometers have scales with 0.10-inch divisions.

Data Recording and Reduction

Forces and moments.- An eight-channel automatic instrument indicates and records model forces, moments, and base pressures. These data are

manually transferred to punched-card form and then reduced to coefficients by machine at the Laboratory's computing center.

Pressures.- The manometers are photographed and the records are read manually with a special device which atuomatically computes and semiautomatically plots the coefficients.

Flow Visualization

Black-and-white and color schlieren equipment is available for visual observation and photographic recording of the characteristics of the air flow about models. Schlieren observations made during normal three-component testing are in the direction of the model lift axis since the plane of pitch and the light beam are both horizontal. Side-view schlieren observations to show the effects of changes in angle of attack on the wing shock-wave patterns require special setups employing bent stings.

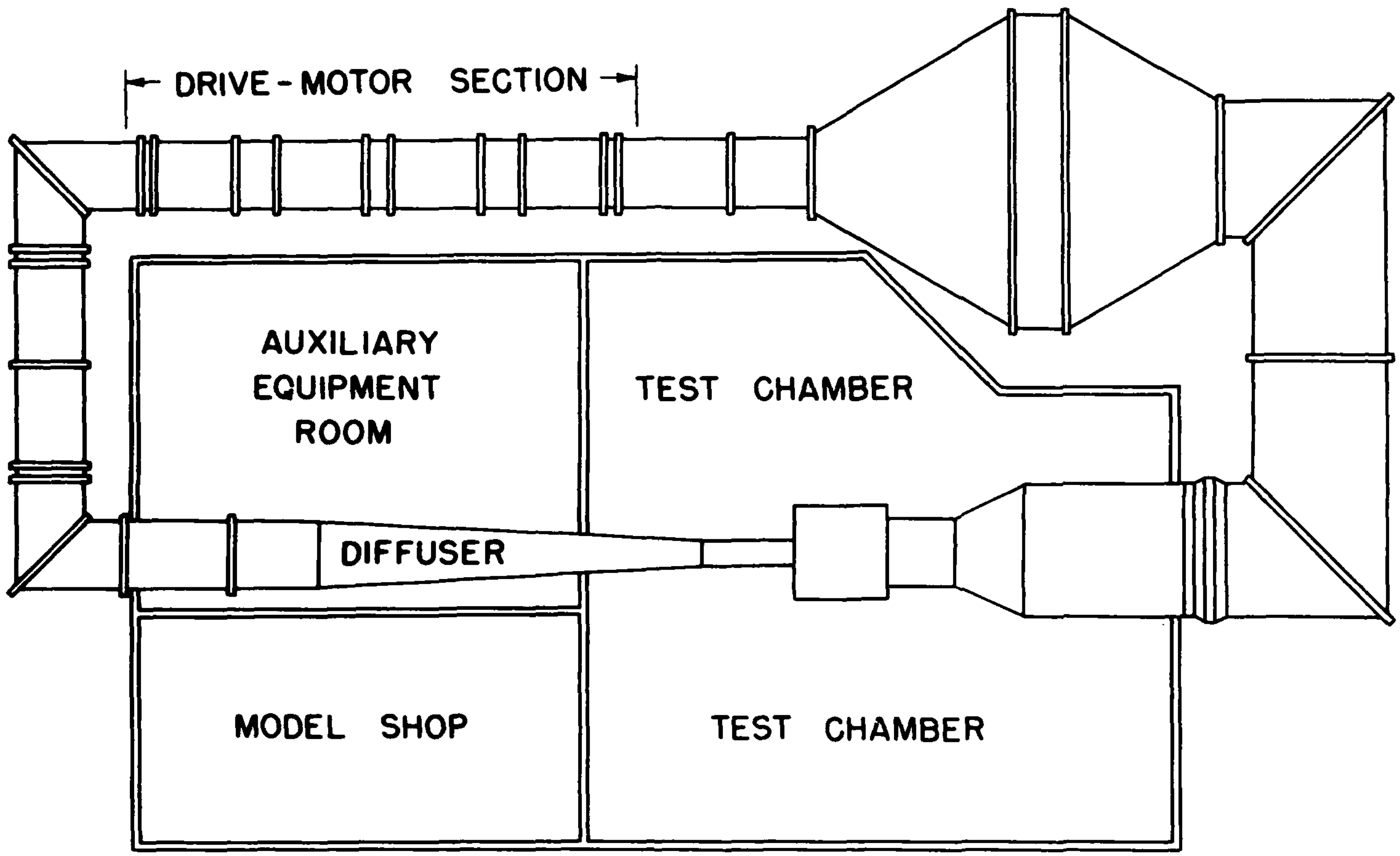


Figure 1.- Ames 2- by 2-foot transonic wind-tunnel circuit and building floor plan.

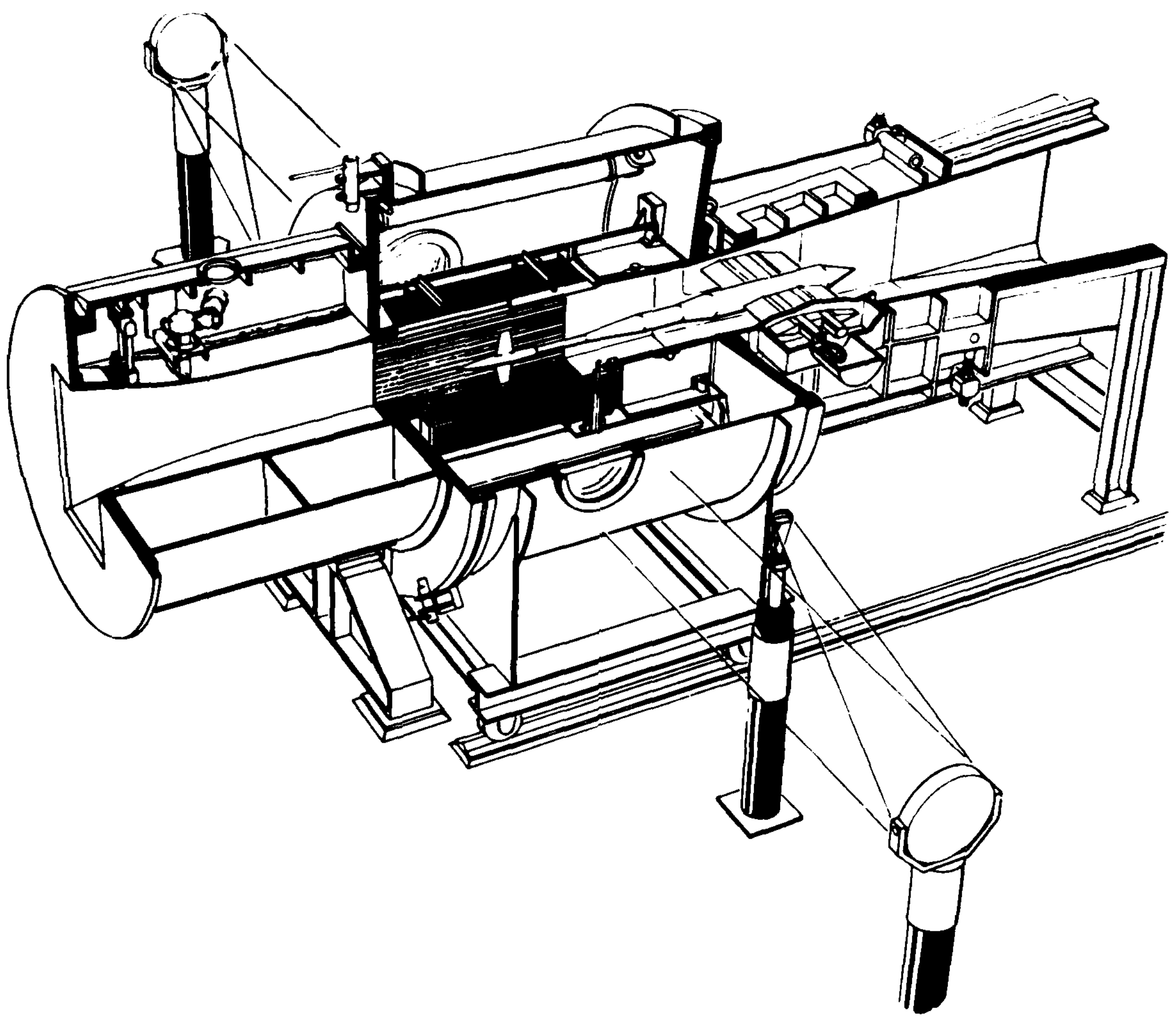


Figure 2.- Sectional perspective view of the nozzle and test section of the Ames 2- by 2-foot transonic wind tunnel.

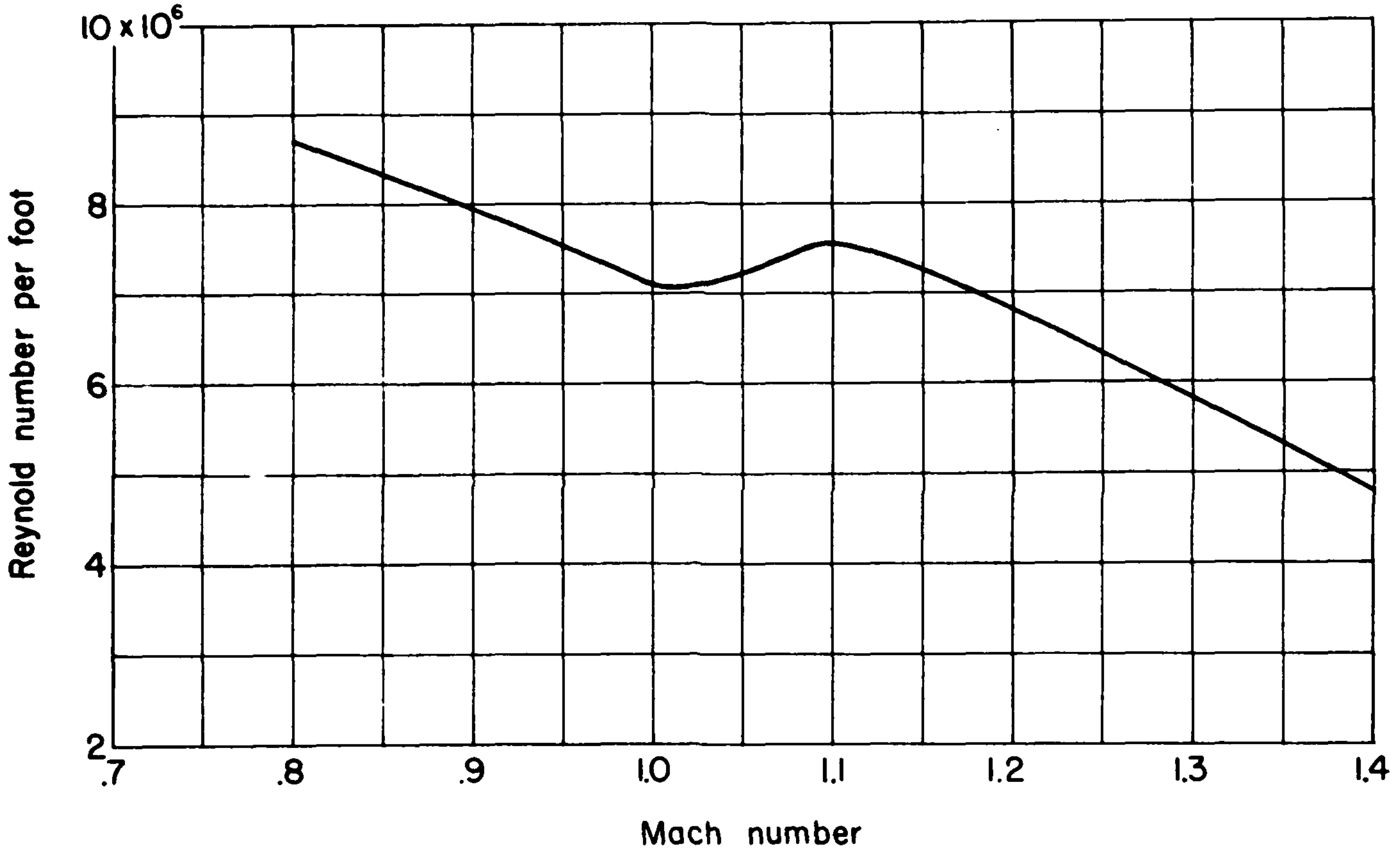


Figure 3.- Variation of Reynolds number per foot with Mach number for approximately maximum motor drive power in the Ames 2- by 2-foot transonic wind tunnel.

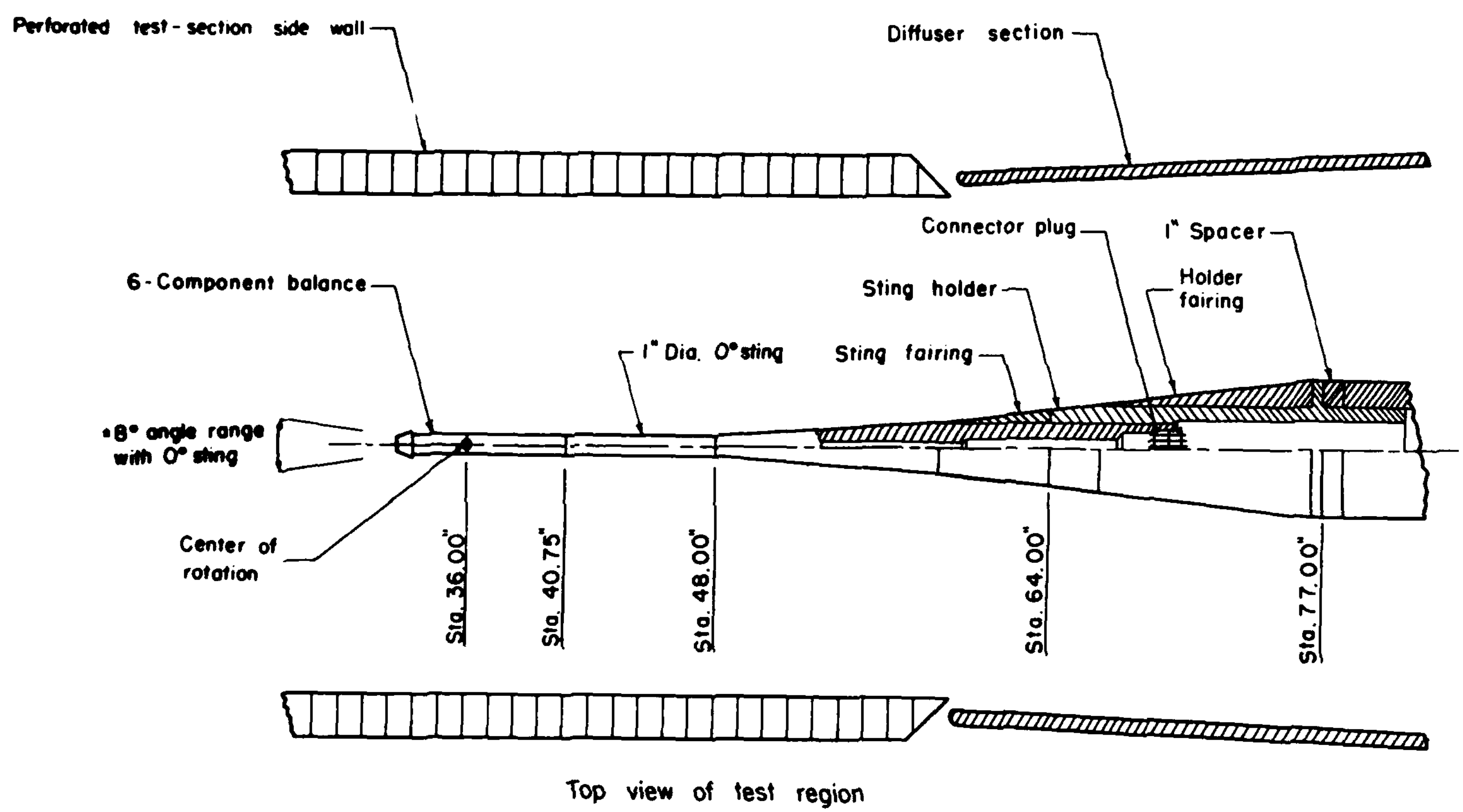


Figure 4.- Ames 2- by 2-foot transonic wind tunnel model-support system.

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THE AMES
1- BY 3- FOOT SUPERSONIC WIND TUNNELS

Ames Aeronautical Laboratory

Moffett Field, California

NACA

GENERAL DESCRIPTION

The Ames 1- by 3-foot supersonic wind tunnels consist of two similar tunnels for research at Mach numbers from 1.4 to 4.0. The No. 1 tunnel is of the closed-circuit type and can operate continuously. The No. 2 tunnel is of the intermittent-operation, blowdown type and utilizes dry air stored in the adjacent Ames 12-foot low-turbulence, pressure wind tunnel. A plan-view drawing of the two wind tunnels and their associated equipment is shown in figure 1.

TEST SECTIONS

The test sections of the two wind tunnels are rectangular in cross section. They consist of the fixed, parallel side walls and the flexible plates which form the top and bottom. The general arrangement of this portion of the circuits for the two tunnels is shown in figures 2 and 3.

TEST CONDITIONS

The Mach number is continuously variable in both tunnels from 0.4 to 0.9 and from 1.4 to 4.0. In the No. 1 tunnel, the Mach number can be changed during operation; in the No. 2 tunnel, shutdown is required for changing the Mach number. The stagnation pressure and the Reynolds number are variable in both tunnels. Reynolds number as a function of Mach number for available total pressures is presented in figures 4 and 5 for the two wind tunnels. The stagnation temperature is controllable between 60° and 140° F in the No. 1 tunnel. In the No. 2 tunnel, the stagnation temperature is not controllable and varies from an initial temperature of about 70° F to as low as 0° F after a long run.

MODEL-SUPPORT SYSTEM

Each wind tunnel is provided with two types of model-support systems: sting-type supports for complete models and side supports for two-dimensional or semispan models.

External-Balance Sting-Support System

For this system, the model is mounted at the rear on a sting which is held in place by a four-arm structure (quadripod) from the test-section side walls as shown in figure 6. The quadripod is attached to each side of the test section by rotatable rings which are concentric with the windows. This arrangement provides angle-of-attack variation (in the vertical plane) of the model about the window axis. The range of these angles depends upon the test-section height: ±0° with a height of 20 inches to ±25° with a height of 34 inches. The angle range can be shifted by mounting the model on a bent sting. Tests of the model in sideslip can be performed after rotating the model 90° about its longitudinal axis. Tests in combined pitch and sideslip are provided for by stings bent in a horizontal plane. Because of the small test-section width, only a small amount of bend (about 5° maximum) can be used for these tests. A motor-driven mechanism that rolls sting-supported models ±180° is available. This mechanism does not attach to a balance and is suitable for pressure-distribution or flow-visualization tests only.

Internal-Balance Sting-Support System

A support system providing large simultaneous variations in vertical-plane angle and roll angle is also available. It is similar to the quadripod system except that it is much smaller and has only one strut spanning the tunnel between the rotating rings. A pictorial view of this support is shown in figure 7. Because of the small size, it is necessary to use balances internal to the models for force tests with this support system. Pressure-distribution models can also be mounted on this support. The vertical-plane angle range is ±45° for large test-section heights and approximately ±30° when the minimum test-section height of 18 inches is used. Sting offsets will be available to allow angles of attack from 0° to 90°. The model can also be rolled about its longitudinal axis for the complete ±180° angle range.

Side-Support System

For this system, a half (semispan) model is mounted through a boundary-layer bypass plate and is connected to a balance-support system which is external to the wind tunnel. The model and support system can be rotated through an angle-of-attack range of ±45°. For tests of two-dimensional models, a side-support system is mounted on each side of the wind tunnel as shown in figure 8. The side-support system with a balance can also be used with pressure-distribution models.

Typical model installations are illustrated in figures 6, 7, and 8. It is essential that the wind-tunnel staff be consulted early during the planning of any investigation to assure that the latest of the continuously evolving techniques and equipment will be used to best advantage. Such consultation should be held before detailed model design is begun in order to make the best selection from the many possible methods of attaching models to the various balances and support systems. Details of mounting dimensions and of other equipment and instruments can be supplied at this time.

The model size is determined primarily by consideration of the minimum Mach number of the test, the model-support system, and the model configuration. The approximate maximum dimensions of models for each of the support systems are listed in the following tables:

Sting Support (Complete Models)

Mach No.	Body length, in.	Body diameter, in.	Wing span, in.
1.5	11	1.5	6
2.5	15	1.5	7
3.5	16	1.5	8

Side Support (Half Models)

Mach No.	Body length, in.	Body diameter, in.	Wing span, in.
1.5	20	2	5
2.5	25	2.5	6
3.5	25	2.5	7

INSTRUMENTATION

Balances

Sting-type, side-support, and internal strain-gage balances are available for measuring forces and moments acting on models. Dimensions and capacities of these balances can be ascertained by consultation with the wind-tunnel staff.

Manometers

Each of the 1- by 3-foot tunnels has identical manometer systems. Each manometer consists of a bank of 120 tubes. The fluids used are mercury, tetrabromoethane, and silicone (DC-200). The scales are labeled in inches and are graduated in 0.10-inch divisions. The manometers are back-lighted and the data are recorded by automatic 70-mm cameras. The working height of these manometers is 150 inches.

Data Recording and Reduction

Each of the 1- by 3-foot wind tunnels has the same data-recording equipment. Four channels of strain-gage output are printed simultaneously. Up to 120 pressures are recorded photographically by a 70-mm camera. As many as 12 temperatures are recorded by a Brown thermocouple-recording potentiometer. Schlieren pictures and model angle are recorded by an automatic 70-mm camera in the schlieren system. A reading number appears on each of these records to correlate the data. All records are read and transcribed on a master data sheet. These data can be manually computed or punched into cards and the results calculated by electronic computing machines at the Laboratory's central computing facility.

New automatic data-processing systems are under development and are estimated to be available after July of 1958. Again, each of the 1- by 3-foot tunnels will have the same basic system. For pressure tests, an analog coefficient computer will be provided. An automatic plotter will plot pressure coefficients as a function of location while the test is in progress. The raw data will also be punched on paper tape which can be processed at the central computing facility for accurate evaluation of the final results if required. For force tests, the raw data will be punched on paper tape and recorded by electric typewriter. The tape may be processed after each run at the central computing facility where the final results are plotted and tabulated.

Flow Visualization

Optical glass windows 18 inches in diameter are mounted in frames and act as doors to close the 24-inch-diameter openings in the side walls of both test sections. These windows permit observation by schlieren, shadowgraph, or direct photography. An additional window 4-1/2 inches in diameter is in the top of the test section of the No. 1 wind tunnel 2 inches downstream of the center of the side-window openings. The "vapor screen" method can be used in the No. 1 wind tunnel for the study of vortex flows.

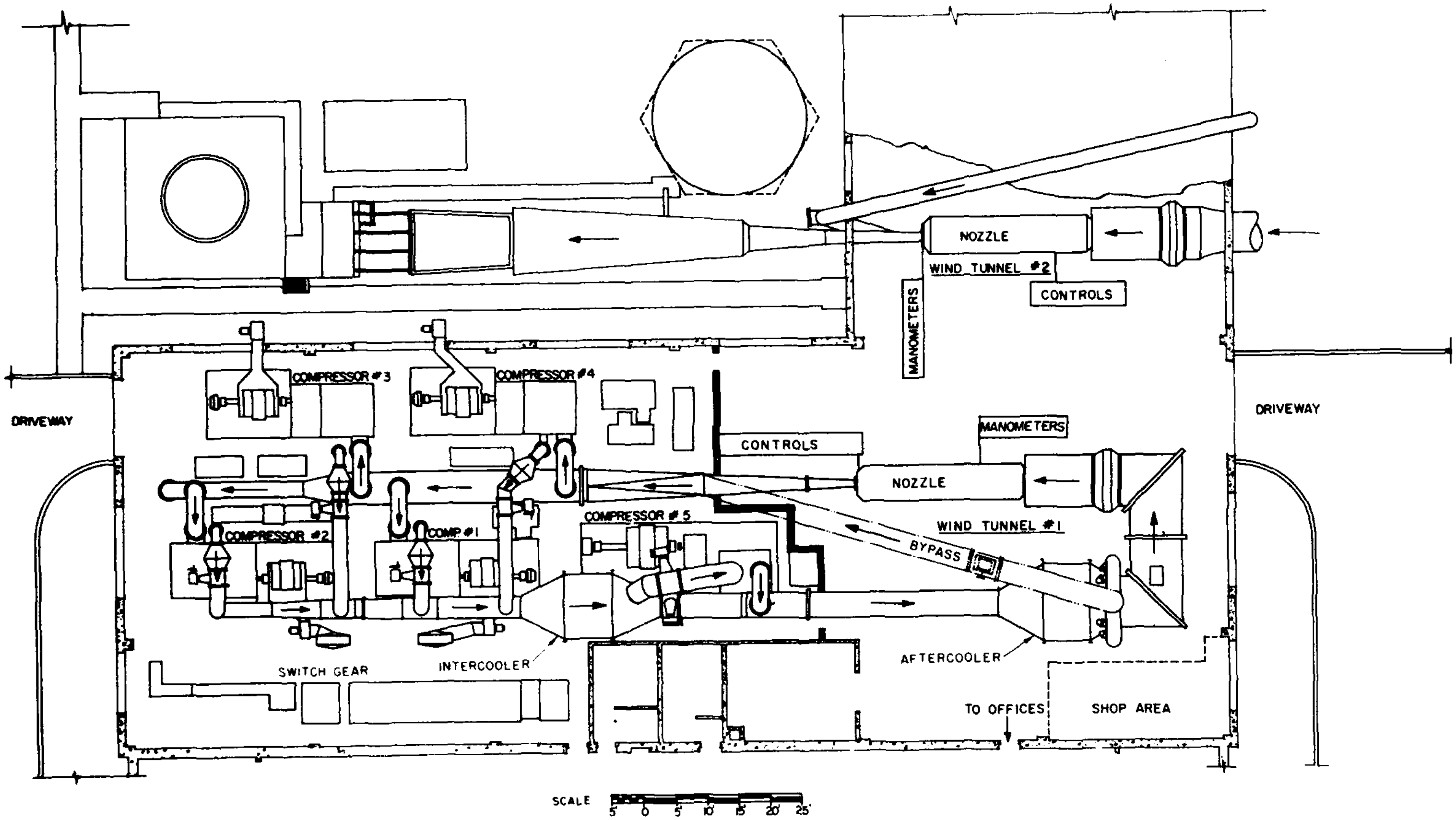


Figure 1.- Plan view of Ames 1- by 3-foot supersonic wind tunnels and building.

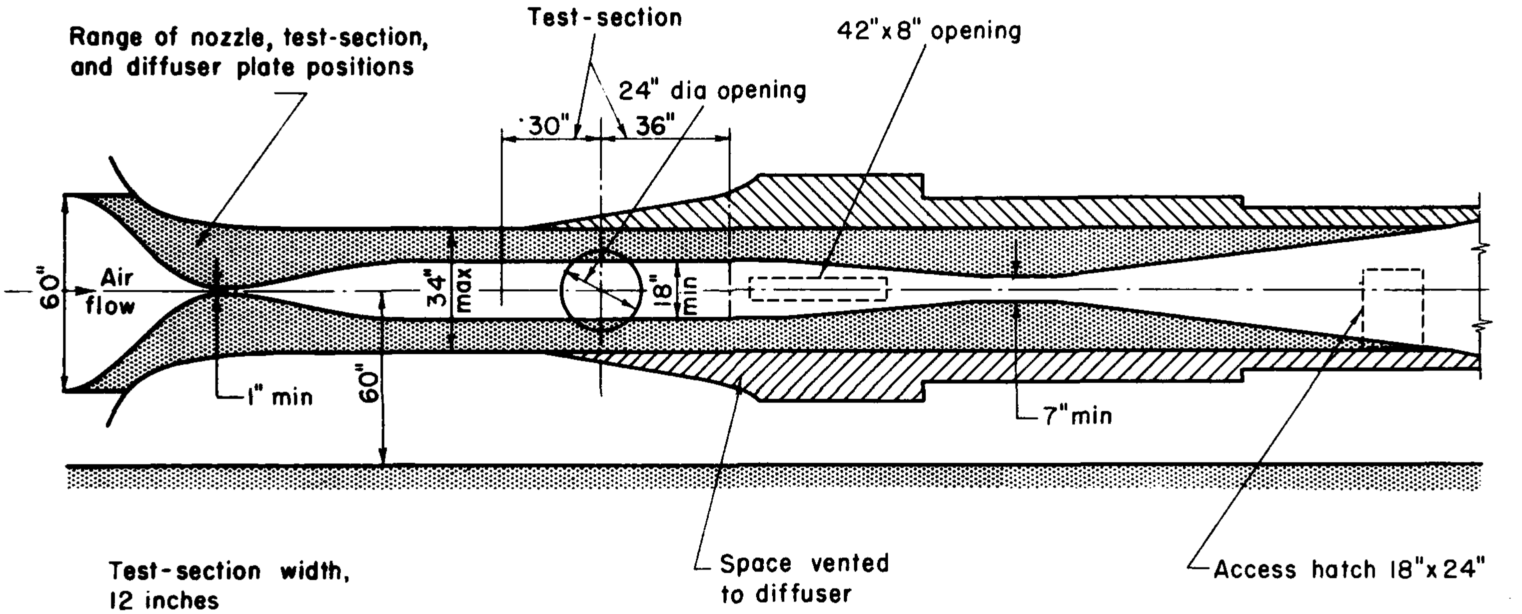


Figure 2.- Diagram and dimensions of the nozzle, test section, and diffuser of the Ames 1- by 3-foot supersonic wind tunnel No. 1.

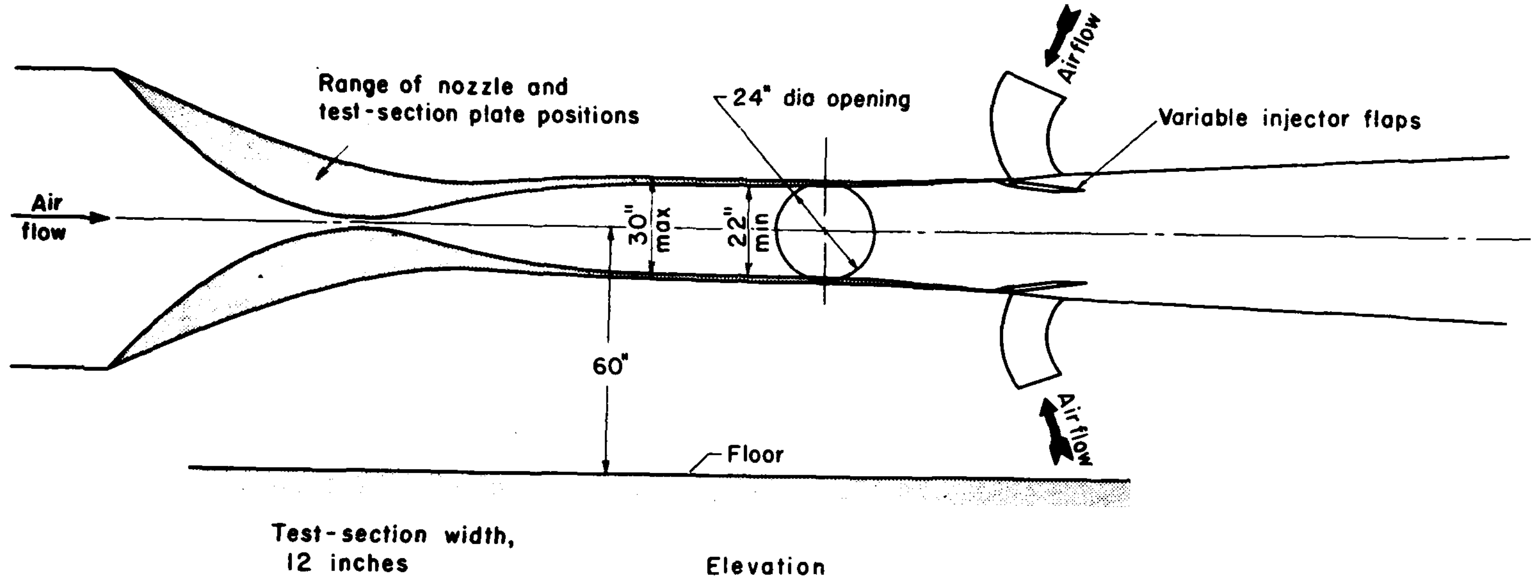


Figure 3.- Diagram of the nozzle, test section, and injector of the Ames 1- by 3-foot supersonic wind tunnel No. 2.

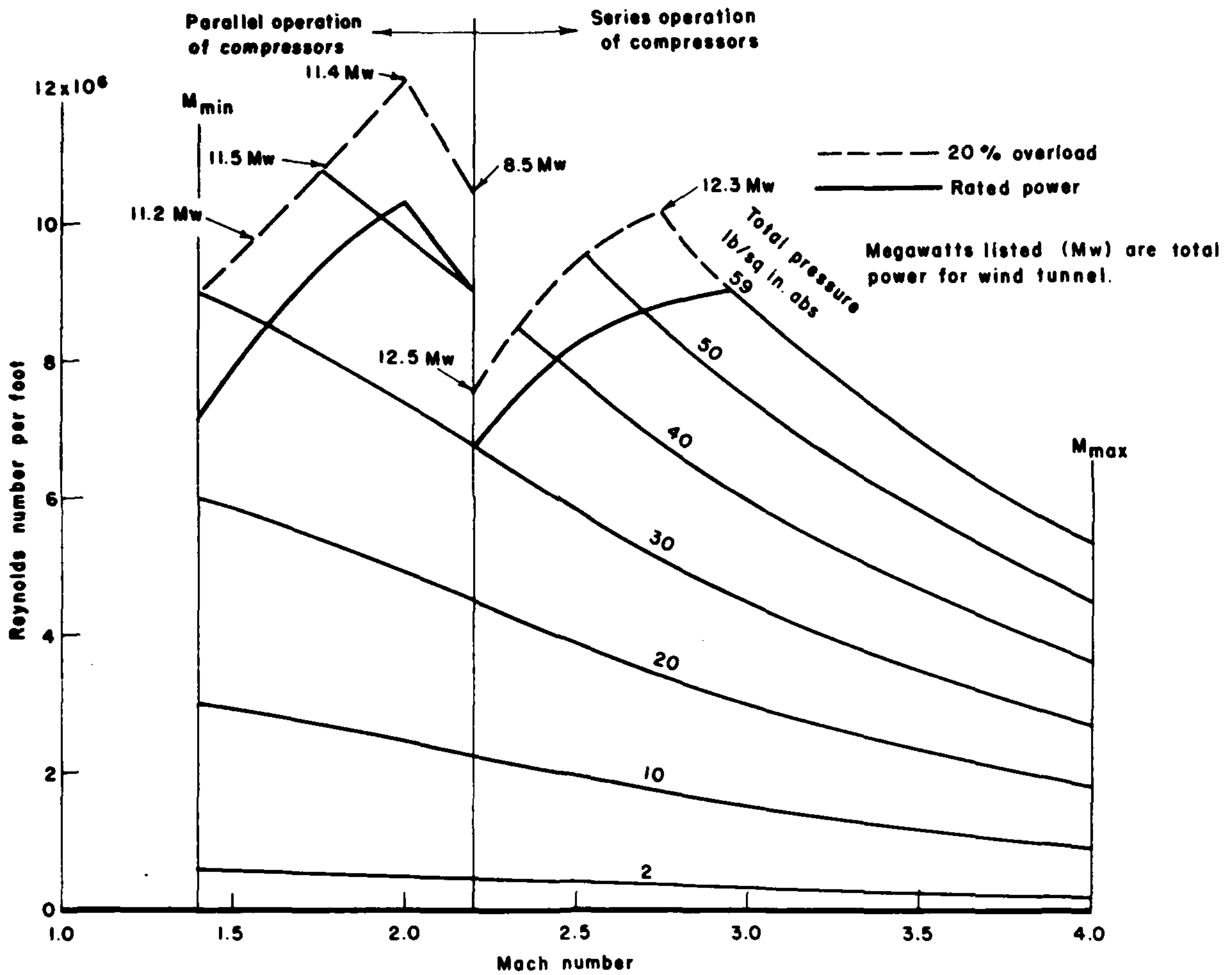


Figure 4.- Range of test conditions in the Ames 1- by 3-foot supersonic wind tunnel No. 1; stagnation temperature = 100° F.

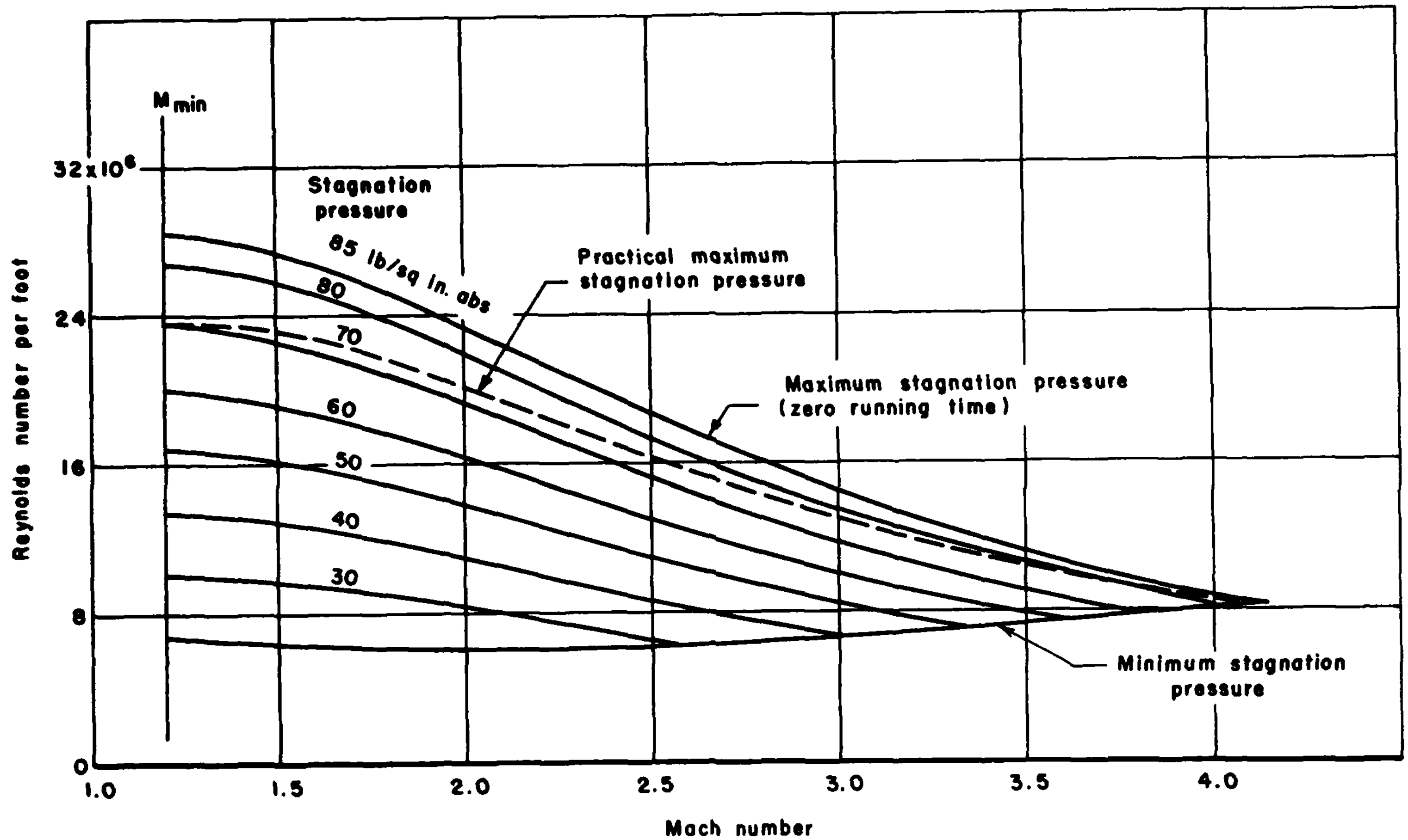
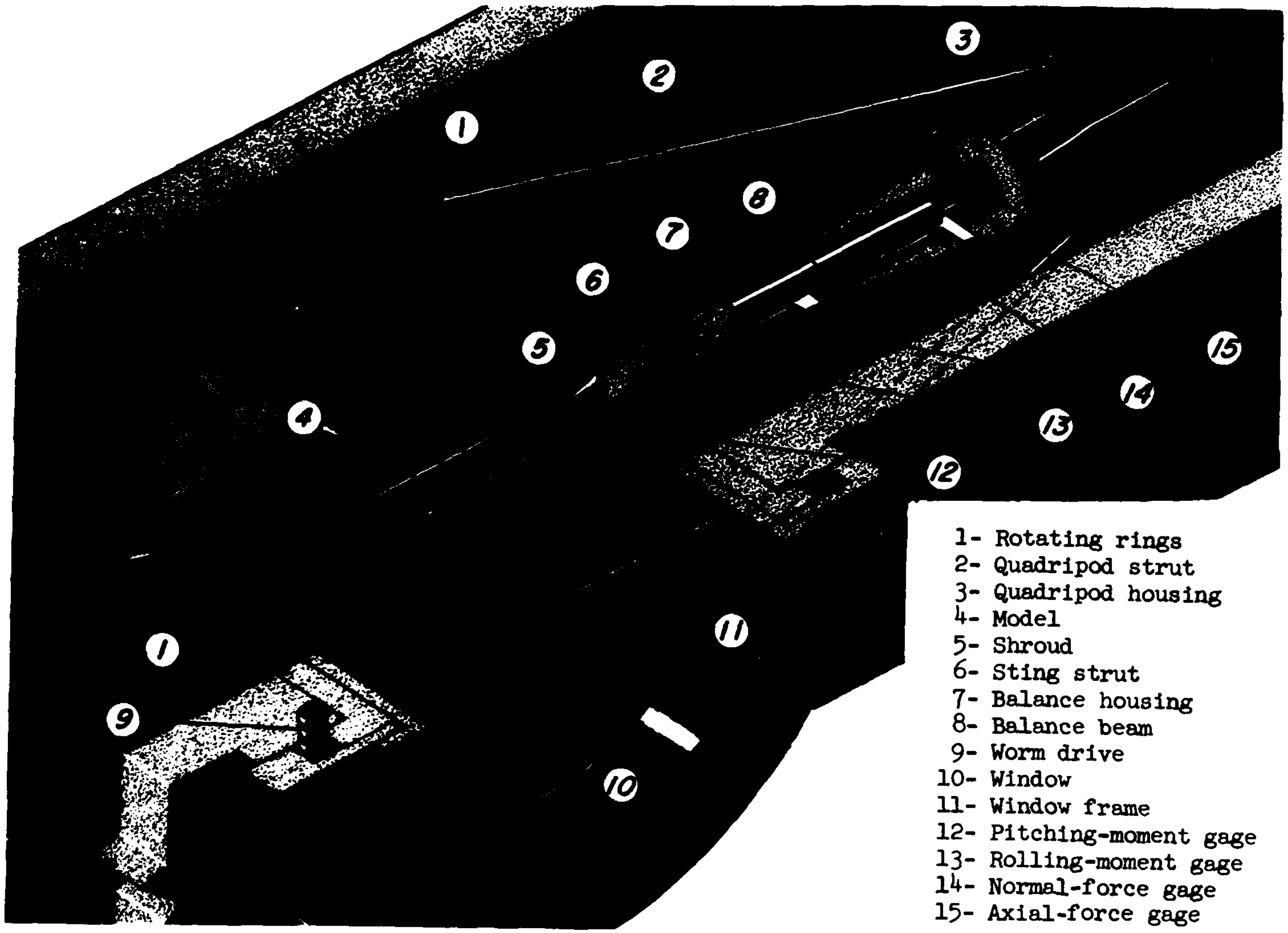


Figure 5.- Range of test conditions in the Ames 1- by 3-foot supersonic wind tunnel No. 2; stagnation temperature = 60° F.



1- Rotating rings
2- Quadripod strut
3- Quadripod housing
4- Model
5- Shroud
6- Sting strut
7- Balance housing
8- Balance beam
9- Worm drive
10- Window
11- Window frame
12- Pitching-moment gage
13- Rolling-moment gage
14- Normal-force gage
15- Axial-force gage

Figure 6.- Support system and balance for rear-supported models in Ames 1- by 3-foot supersonic wind tunnels.

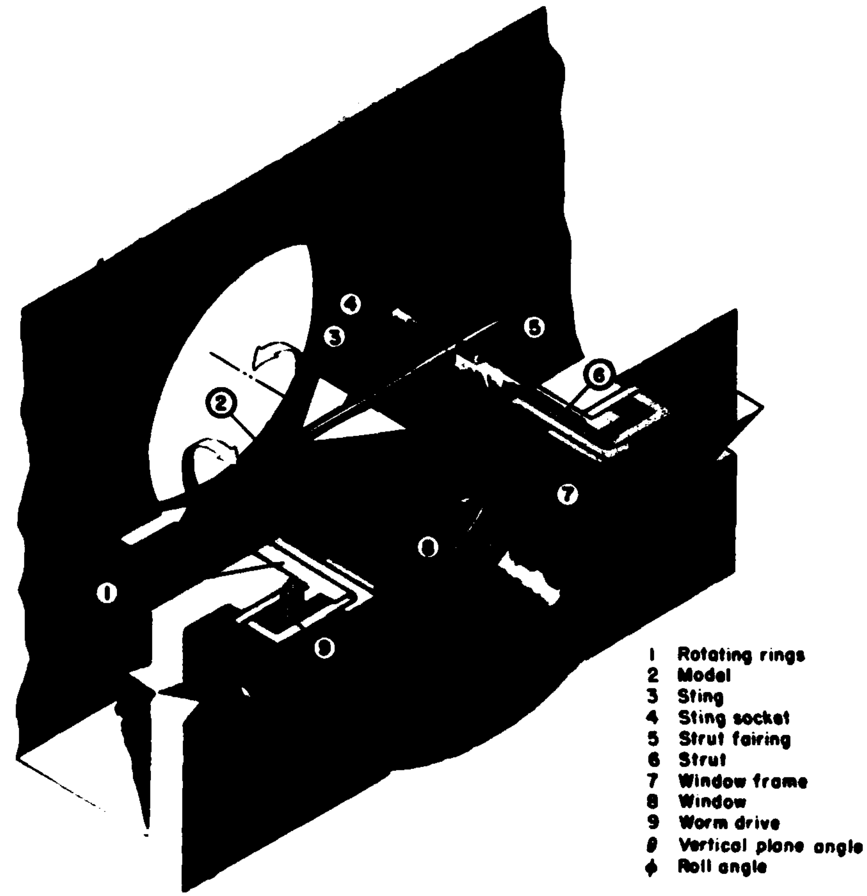
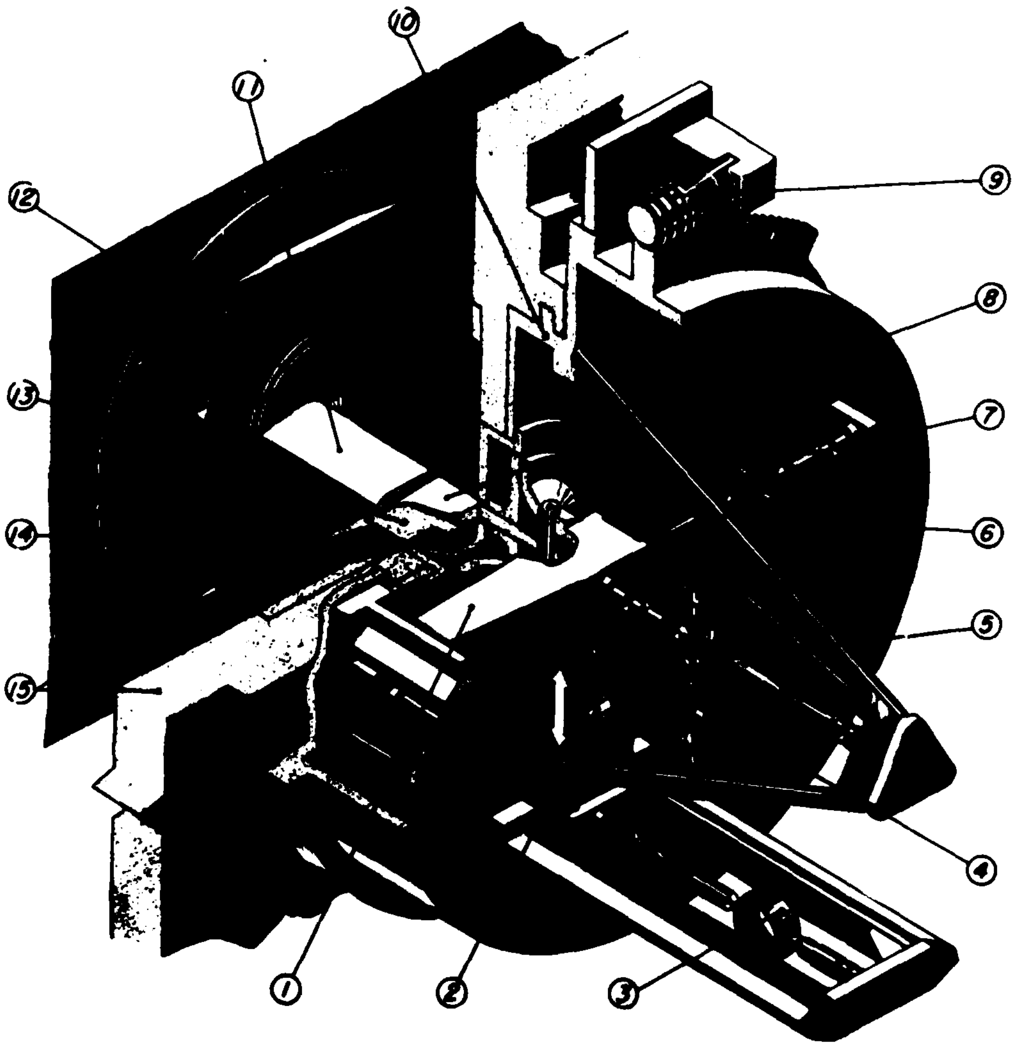


Figure 7.- Internal-balance support system in Ames 1- by 3-foot supersonic wind tunnels.



1.- Floating beam
2.- Normal-force gage
3.- Rolling-moment gage
4.- Pitching-moment gage
5.- Side-force gage
6.- Pin connecting model shank to floating beam
7.- Chord-force gage
8.- Model shank
9.- Worm-gear drive mechanism
10.- Balance housing
11.- Two-dimensional model
12.- Rotating circular plate
13.- Fairing
14.- Boundary-layer plates
15.- Main tunnel walls

Figure 8.- Side-support balance system in Ames 1- by 3-foot supersonic wind tunnels.

ERRATA

CHARACTERISTICS OF SIX RESEARCH WIND TUNNELS OF AMES AERONAUTICAL LABORATORY

NACA, 1957

Insert the attached page 20 (fig. 2 of section "Ames 14-Foot Transonic Wind Tunnel"), which was inadvertently omitted in the original assembly of this manual.